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AGARD LECTURE SERIES No.156

Visual Effects in the High Performance Aircraft Cockpit

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— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

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ABSTRACT

Visual is the key sensory mode by which a pilot receives the vast majority of the information required to successfully fly the aircraft and accomplish his mission. Visual information is received both directly (viewing through the windscreen, heads-up display and visor) and indirectly (viewing instruments, graphics displays and imaging displays) in a continuous stream. The ability of the pilot to perceive, assimilate and act on this vast amount of visual information greatly depends on the quality of the presentation of this information. There are many factors that can reduce the effective visual capability of the pilot. It is the purpose of this Lecture Series to present many of these factors and discuss their effect on vision and visual performance.

This Lecture Series, sponsored by the Aerospace Medical Panel of AGARD, has been implemented by the Consultant and Exchange Programme.

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Le mode visuel est le mode sensoriel clé, qui fournit au pilote la majeure partie de l'information dont il a besoin pour piloter son appareil et mener à bien sa mission. Il reçoit cette information visuelle soit directement (pare-brise, visualisation tête haute, indicateur monté sur casque) soit indirectement (écrans de vision, affichages graphiques, affichages à imagerie) comme un flot ininterrompu d'informations.

La capacité du pilote à recevoir et assimiler ce volume énorme d'informations visuelles pour ensuite agir en conséquence, dépend, en grande partie, de la qualité de présentation de ces informations.

Les facteurs susceptibles de réduire les capacités visuelles effectives du pilote sont nombreux. L'objet de ce cycle de conférences est de présenter un certain nombre de ces facteurs et d'examiner leurs incidences sur la vision et les performances visuelles.

Ce cycle de conférences est présenté dans le cadre du programme des consultants et des échanges, sous l'égide du Panel AGARD de la médecine aérospatiale.

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iii

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CONTENTS

v

VISUAL EFFECTS IN THE HIGH
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INTRODUCTION

The modern high performance aircraft is a product of a very fast development caused by reaction and counterreaction to the actual and perceived threat from possible adversaries. It has become a very complex and specialized tool in the hand of the operator, the pilot. The pilot, on the other hand, has not undergone a similar development. He is still the basic creature which evolution has made suitable for walking on two feet at moderate speeds on the surface of the earth. The necessary skills to survive was developed by an evolution of his brain and not his physical/sensory qualities. His brain has made him capable of designing survival tools (here the high performance aircraft). In this lecture series we have been asked to take a look at whether he has adapted this tool to his sensory system (here his vision).

Until recently the socalled man-machine interphase requirements seem to have suffered under the requirements for technical performance. We have prob:bly not seen one single type of aircraft without a major human factors design defiency. It is obvious, though, that now there is fortunately a much improved understanding for the need to research in this field and to design equipment with a total view on effectiveness: Technical performance, man-machine interphase, maintainability etc. etc. The need for close cooperation and crosstalk between the researcher, the equipment designer, the operator and the maintainer has been broadly acknowledged and the composition of lecturers for this lecture series is a good example of this.

The subject is visual effects in the high performance aircraft cockpit. The idea of the lecture series is an attempt to look at the efforts to enhance the visual environment for the pilots from the points of view of many different shareholders to the problem:

- Eye physician
- Research physicists
- Test pilot
- Supervisor of flying/flight safety officer
- Maintenance officer

The lectures as a whole should give an overview of the visual problem from state of the art scientific knowledge to every day maintenance practise.

The lectures have been asked to contribute based on their specialized knowledge on the topics and/or their background experience. The lectures stand by themselves and the content may be factual, speculative or just an opinion based on experince and intuition and the content is the responsibility of the author alone. He will during the discussion period be willing to debate all the covered issues and also a elaborate on specific points of interest.

The overwhelming majority of the inputs to the pilot necessary to fly and fight with his aircraft are transmitted via the eyes. Some of these inputs are processed by the conscious brain and are therefore easily adaptable by training and experience. Others are processed by the unconscious brain and require a much more delicate approach to design and training. The visual

environment in the cockpit varies immensely dependant on night or day and weather effects. Under these varying conditions all transparencies, instruments, display systems, paint schemes etc. should offer the best possible visual inputs, and, which is of crucial importance, must prevent incapacitating visual disorders.

The first lecturer will take a look at the visual sensor itself. He will consider all known aspects of visual physiology relevant to high speed flight. This will encompass visual parameters across the field of varying conditions to include the associated test procedures. Which will lead to his second part, where he will discuss vision enhancement by spectacles and contact lenses, hazards to vision and the protection systems used.

The next paper will discuss problems areas based on vision related accidents/incidents. The lecture will describe the many different break down modes of the required visual capabilitis, based on actual events. The paper is an attempt to bring matter to the theories.

Until recently the important transparencies on aircraft have been made up by flat surfaces. This has been necessary to be able to control the optical qualities of the material used. The requirements for technical performance and also the advances in optical technology have now made it common to use bubble canopies, which are tri-dimensionally curved also in critical areas. The next paper will discuss the optical and visual effects of these aircraft transparencies.

Next and operator/test pilot will discuss visual concerns for general operations and training of aircrew. He will be followed by a maintenance officer who will discuss the very delicate task of maintaining these most fragile parts of the aircraft, which make up the vision related hardware. He will also discuss the very complex techniques for interphasing the different equipment to correspond to the optical devices.

Night vision goggles are now being introduced to expand the operational capabilities of high performance aircraft by providing visual enhancement to the pilot by direct viewing. The next paper will discuss the problems of compatibility between these light amplification devices and the basic cockpit lighting system.

Next this lecturer will discuss the problems of displaying data to the pilot on the various display systems in the cockpit, with sufficient image quality over the full range of ambient light conditions. From direct sunlight to extreme darkness.

Finally we will take a look into the future, which will present the operator and the aircraft designer with a variety of technical devices in the visual arena. Laboratories all over the world are working on new developments. Will we succeed in making these devices well adapted to the operators needs or will the urge for technical performance once again force human factors design disasters into the field?

The lecture series is composed to focus on one very important but very specialized field. We shall remember, though, when we concentrate on a special interest area, that the aim of the game for the high performance aircraft is to go out there to destroy the enemy and survive the effort.

VISION AND VISUAL PROTECTION IN FAST JET AIRCRAFT

by

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SUMMARY

Aircrew flying fast jets such as the F16 require high visual standards in order to be able to react quickly to tactical and emergency situations within their environment.

This paper discusses the basic visual physiology of importance in flight together with the visual standards and associated test methods that are necessary for optimum performance. The paper concludes with a review of the hazards of solar radiation together with suggestions for the optical and spectral quality of visors and corrective eyewear.

BASIC VISUAL PHYSIOLOGY

It is convenient to divide ocular function into its three component parts, namely the detection of light, form and colour.

Light Sense

The eye is capable of functioning over a wide range of illumination levels. The threshold stimulus for the eye is below 10^{-5} lux, and the maximum limit, where discomfort is evident, above 10^5 lux (bright sunlight at altitude). Two mechanisms function over this range. Scotopic or rod vision operates from threshold to approximately 10^{-2} lux and over this range the ability to see detail is poor and vision is monochromatic. Above 1.0 lux, photopic or cone vision is the dominant mechanism giving, with increasing illumination, the twin advantages of good resolution of detail and colour vision. The transitional stage between 10^{-2} lux and 1.0 lux, when both rods and cones are functioning, is known as mesopic vision and ranges roughly between a quarter and full moonlight.

The retina requires time to adjust to varying luminances because the mechanism is photochemical. When the retina adapts from dark to light the adjustment is rapid, but in adapting from light to dark the adjustment is slow and biphasic. As can be seen from the dark adaption curve (Fig 1), there is not a steady increase in sensitivity. The curve is in two portions, the initial adaptation being that of the cones and the slower adaptation, that of the rods. At night in order to read instruments and to recognise terrain features, vision, of necessity is operating in either the low photopic or mesopic regions. A further feature of rod and cone vision is their different colour sensitivity. Rods are most sensitive to blue/green light and cones to yellow/green light (Fig 2). This differing colour sensitivity, which is known as the Pukinjé phenomenon, is evident at dusk when a red colour appears to be dark, whilst a blue colour, subjectively, retains its brightness.
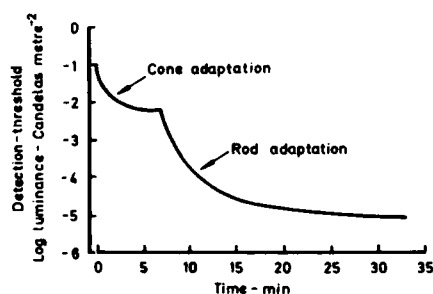
Fig 1. The dark adaptation curve of the eye.
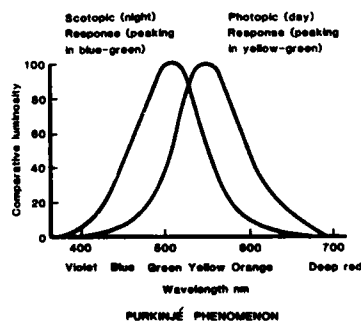
Fig 2. The photopic (cone) and scotopic (rod) spectral sensitivites of the eye.

A consequence of this double mechanism for light appreciation was the adoption of red lighting systems to maintain night vision. It used to be customary to wear red goggles in lighted crew rooms and to use red cockpit lighting since rods, unlike cones, are insensitive to the longer red wave-lengths. The advantage of preserving rod adaptation is, usually, unnecessary as few fast jet roles can be performed with rod vision. In most operations the visual acuity provided by the cones is imperative.

The disadvantages involved with red cockpit lighting systems in interpreting coloured maps and legends, the absence of colour fringes, which are a sub-conscious aid to rapid focussing and the extra focussing effort required to read in red light, far outweigh any theoretical advantage in maintaining rod adaptation.

Form Sense

When one looks at an object it is imaged on the fovea and the surrounding macula. The fovea is a specialised region of the retina composed entirely of cones. It is where vision is clearest and colours are most readily seen. Peripheral to the fovea the retina is composed of both rods and cones, the radio of rods to cones increasing and visual acuity decreasing, with distance from the fovea.

Under good conditions the eye can resolve detail which subtends a visual angle of 30 seconds of arc. However, under some special circumstances much finer resolution is possible. A single line may be differentiated against a plain background when it subtends a visual angle as small as 0.5 seconds of arc. This is more a measure of contrast than of resolution.

Factors which may influence the resolution of the eye are:- atmospheric conditions, the optical quality and cleanliness of interposed transparencies, ocular pathology and the requirement for spectacles. The large pupillary diameters which occur at night may render more evident the visual decrement caused by refractive errors by reducing the depth of field of the eye.

Recognition of objects is also profoundly influenced by the inductive state of the retina. One part of the retina modifies the function of another part. This is known as spatial induction. In aviation, spatial induction will enhance the recognition of targets against the sky. The bright sky diminishes total retinal sensitivity and a grey target, therefore, appears darker, with a consequent increase in the contrast between it and the sky. If the adapting stimulus is coloured the reduction in sensitivity will be hue dependent and complementary colours will be seen more readily. However, a stimulus on a portion of retina will also affect function of that portion to a subsequent stimulus. If a bright object forms an image on a portion of the retina, the sensitivity of that retinal area will be depressed for a considerable period of time. This may cause low contrast targets, imaged on that area, to remain unseen.

Visual acuity is also influenced by contrast between target and background and by the luminance of the target. Sharpness improves with increasing luminance, up to a moderate level, beyond which no further increase occurs and at very high luminances, may be impaired. The best resolution is achieved when the luminance of the target and the ambient lighting are similar; a significant disparity will reduce visual acuity.

Colour Sense

Colour vision is a function of cones and therefore of photopic vision. According to the generally accepted theory of colour vision, there are three classes of cones present at the macula, in the ratio of 1:10:10. These cones have absorption peaks for blue (420 nm), green (534 nm) and red (564 nm) respectively. The combination of the yellow macular pigment filter and the absence of blue cones at the fovea causes central blue blindness for small objects or lights subtending visual angles of less than one degree. A combination of the three primary colours, in the correct proportions, is seen as white light, and by varying the proportions and saturation (addition or subtraction of white light) any other colour can be matched.

A feature of colour vision is the processing of the signal from the eye. The brain "sees" that which it expects to see. If an individual wears coloured spectacles he very rapidly adjusts to the colour change and he then "sees" objects in the colours he would expect and mistakes can occur. A similar phenomenon occurs with form vision when the eye is presented with limited information. The brain may fill in the remainder of the scene it is expecting to see, resulting in gross errors of interpretation.

VISUAL FUNCTION IN FLIGHT

There are a number of visual problems which are peculiar to aviation and the following are particularly relevant.

Reaction Times and Aircraft Speed

It is estimated that in excess of 75% of flight information is acquired visually. Modern military aircraft, such as the F16, frequently operate at high speeds and if accidents are to be avoided other aircraft must be seen as rapidly as possible. There is an irreducible period of some 5 to 6 seconds which will necessarily elapse between an object being detected on the peripheral retina and the aircraft changing course. This elapsed time includes the periods required for foveal fixation, focussing, to make a decision on the necessary action required, to take that action and for the aircraft to respond to the controls. Should the aircraft be travelling at 750 knots the pilot must see another aircraft on a collision course at a minimum distance of 1.0 nautical mile if a collision is to be avoided. The distances increase

with higher speeds and should two aircraft be on a head-on collision course, they may be doubled.

Empty field myopia occurs when the eye is deprived of visual cues at infinity. In ocular terms this is any distance in excess of 6 metres. Under these conditions the eye frequently focusses to between 1 and 2 metres making the aviator temporarily short-sighted. Should another aircraft enter his field of view it may not be seen due to blurring of the retinal image. The conditions likely to cause this problem are flight at night, when it is known as dark focus, in cloud or whilst flying over featureless terrain. Aircrew should periodically look at ocular infinity, at objects such as their wing tips, in order to relax their accommodation. The conditions causing empty field myopia may also cause feelings of detachment and isolation - the "Break Off" phenomenon.

Vibration in some aircraft such as helicopters, may cause great difficulty in reading flight instruments, maps or charts. The vibration frequencies, in fast jets such as the F16 during high speed low level flight, are likely to be below 1 Hz with superimposed frequencies of between 10 - 20 Hz during tight turns. These frequencies are, in practice, unlikely to cause any significant visual decrements.

Autokinesis may occur whilst looking at lights, such as stars or aircraft navigation lights, against blank backgrounds. After a short interval the lights appear to wander randomly. These apparent movements occur if the background does not provide sufficient information about the normal involuntary eye movements. These movements are then interpreted as movements of the lights. This phenomenon may occur during the hover at night, when single lights are seen against a featureless terrain, particularly when the lights are on moving vehicles. Autokinesis was one reason for the abandonment of ultra-violet instrument lighting. The glowing phosphors on pointers and numerals, particularly when background illumination was inadequate, provided the conditions required for the illusion.

Flicker, produced by anti-collision lights and strobes can cause epileptiform episodes. The problem arises when the frequency is between 5 and 20 Hz being maximal at about 12 Hz. Modern strobe lights, normally, have a flash frequency below 2 Hz and should be harmless.

FORM VISION AND TEST PROCEDURES

Entry visual standards of aircrew vary widely between nations. The pragmatic approach of tailoring visual standards to the availability of recruits is often the determining factor. It is sometimes assumed that because spectacles or other visual aids will restore vision to the level demanded, the disadvantages associated with their use are relatively unimportant. This may not follow as will be discussed later.

Form Vision (Static)

The appreciation of shape and detail is largely dependent upon the dioptric mechanism producing a sharply focussed image on the retina, particularly at the fovea, of an object, at any required distance from near to infinity. This ability to produce a sharp image is dependent not only on the eye being emmetropic but also on its accommodative ability. Ametropes may either consciously or subconsciously develop techniques to minimise their disability. Myopes whose far point is nearer than ocular infinity may, briefly, improve distance vision by 'screwing' their eyelids or by rapidly blinking, thereby decreasing their effective pupillary aperture and thus increasing their depth of field. These tricks are only partially effective, particularly under low light conditions, and are fatiguing to maintain. Conversely hypermetropes, whose far point is beyond infinity, require to accommodate to see clearly at distances of 6 metres or greater. This reduces the availability of accommodative power to see near objects, particularly under red lighting. Maintaining constant accommodation is also fatiguing especially when stressed and the amplitude decreases with age. Compensation for astigmatism dependent on type and extent is more difficult.

Form Vision (Dynamic)

When attempting to resolve detail in a moving target the eye must track the object of regard and attempt to maintain steady fixation on the fovea and surrounding macula. The pursuit mechanism is capable of maintaining such fixation with angular velocities not exceeding 30°/s, should the angular velocity exceed 40°/s the visual acuity is likely to drop to 50% of the static acuity. Further losses will occur with increasing velocities.

Examination Procedures

The Snellen test type is the standard test of vision, in which letters of diminishing size are presented on a chart illuminated by 500 - 1000 lux. The letters are black on a white background and are thus of high contrast. At the normal test distance of 6 metres the 6/6 (20/20) letter subtends 5 minutes of arc and the detail within the letter, such as the gap in a C, subtends one minute of arc. This visual angle produces an image size of 2 - 3 μm, which is approximately the diameter of a foveal cone.

Visual acuity is the ability of the eye to discriminate detail and is a measure of foveal function. It may be expressed as the reciprocal, measured in minutes of arc, of the angle subtended at the eye by the detail resolved. The normal method of recording visual acuity in the UK is the metre system: 6/6 means that the eye is able to resolve at 6 metres, detail which the "normal" eye should be able to resolve at that distance. 6/60, for example, means that the eye is only able to resolve at 6 metres that which the "normal" eye can resolve at 60 metres. The converse applies to 6/4 when the eye resolved at 6 metres that which the "normal" eye can only resolve at 4 metres and vision is thus better than normal. The US system is expressed in feet, (Fig 3) gives the approximate equivalences of the UK, US and metric systems.

U.K.	U.S.	METRIC
6/3	20/10	2.0
6/4	20/13	1.5
6/4.6	20/15	1.3
6/5	20/16	1.25
6/6	20/20	1.0
6/9	20/30	0.7
6/12	20/40	0.5
6/15	20/50	0.4
6/18	20/60	0.3
6/21	20/70	0.28
6/24	20/80	0.25
6/30	20/100	0.2
6/36	20/120	0.16
6/60	20/200	0.1

Fig 3. Approximate visual acuity
equivalences, common values underlined.

The testing of distant and near visual acuity is important and should not be delegated to untrained personnel. The candidate should be seated 6 metres from the chart in a room, which is also illuminated to similar level as the Snellen chart, with all glare sources shrouded. The eye not being tested should be covered and the tested eye observed to ensure that the candidate does not 'screw' or rapidly blink. Should he do so, it can be prevented by applying upward pressure on the eyebrow, over the supra-orbital ridge, ensuring that pressure is not applied to the globe. The smallest line at which no errors are made is recorded and that eye is then covered by the examiner, before a new chart is presented to the other eye, to preclude learning.

The testing of the amplitude of accommodation or near vision should be carried out in each eye separately, with and without the normal distance correction, if necessary, and then binocularly. Useful instruments are the RAF or equivalent Near-Point Rules; these rest against the patient's face below the infra orbital margins and permit a rotating carrier of reduced Snellen types to be brought towards the eyes. Having determined the nearest distance at which the appropriate type is correctly read it is possible to read the accommodative ability in dioptres and to compare this with the age related mean Duane limits. The visual acuity standards required for initial selection for training as a pilot or navigator should be such that trained aircrew do not require to wear corrective lenses in order to achieve normal vision until the normal reduction of the amplitude of accommodation, which usually becomes evident in the fourth decade, necessitates the use of corrective lenses for reading. This situation can be achieved by raising the visual standards required for entry into pilot/navigator training.

Visual Acuity Standards

The entry visual standards for fast jet aircrew, such as the F16, vary widely between nations. It is common, however, to require that the corrected visual acuity in each eye be at least 6/6 (20/20) with strict limits on the uncorrected visual acuity. Recommendations for standards, where the availability of recruits permits, are given below.

RECOMMENDED VISUAL STANDARDS

The unaided visual acuity at 6 metres should not be less than 6/6 in each eye separately.

The accommodation in each eye should be at least the mean for age, as defined by Duane. This, in conjunction with limits on hypermetropia, will ensure that aircrew are unlikely to require a presbyopic correction prior to 45 years of age.

Permissible Refractive Errors

The refractive range for each eye should be within the limits $0 - +1.75m^{-1}$ in any meridian, the astigmatic element not exceeding $0.5m^{-1}$. A significant family history of myopia warrants special attention. A refraction under cycloplegia is at the discretion of the examiner but if performed should be followed by a post mydriatic test of visual acuity.

Ocular Muscle Balance

The presence of a manifest strabismus or heterotropia normally precludes aircrew training. Orthophoria is, however, rare and minor degrees of latent strabismus or heterophorias are acceptable in flight provided that the fusional ability of the eyes and the primary distance cue of stereopsis are not impaired. Heterophorias of large extent may be well controlled at rest, but under stress or fatigue control may be lost resulting in symptoms that may include diplopia.

The presence of heterotropias or heterophorias is best detected by means of the simple cover test. This test should be applied at about 0.5m and infinity by requiring the candidate to fixate, sequentially both near and far lights. Each eye is then covered in turn. Should the uncovered eye move to take up fixation it denotes a manifest strabismus and the degree and direction of movement denotes its magnitude and type. This can also be detected by observing the position of the reflections of the fixation light on the cornea, normally these are central. Should a manifest strabismus not be present, the movement of the covered eye should be observed both when first covered and then when the cover is removed. If the eye moves in one direction when covered and in the opposite direction when removing the cover it denotes the presence of a latent strabismus or heterophoria, the type and magnitude again being dependent on the direction, excursion and speed of movement.

Heterophorias can be measured using the standard Maddox Wing or Rod Tests for near (0.3m) and the Maddox rod for far ($>$ 6m). The convergence ability of the eye is best determined using one of the near point rules. Should a candidate be outside the limits for acceptance he should, at the discretion of the examiner, be subject to an orthoptic review.

The ocular muscle balance should be within the following limits:

Distance:	Eso 6cm/m to Exo 6cm/m; hyperphoria not to exceed 1.0cm/m.
Near:	Eso 8cm/m to Exo 8cm/m; hyperphoria not to exceed 1.0cm/m.
Convergence:	To be 10cm or less.

Media and Fundi

There should be no evidence of pathology which could impair visual performance either at the time of the examination or in the near future. Any abnormal finding must be assessed by an ophthalmologist experienced in the visual requirements of high speed flight.

Visual Fields

The field of each eye should be full. The fields to be measured preferentially on a perimeter or failing that by confrontation.

SPECIAL1 JED EXAMINATION TECHNIQUES

Contrast Sensitivity with Gratings

The standard Snellen Test type presents a high contrast target of black letters on a white background and is a measure of the resolving ability of the eye. Vision in flight involves more than the detection of high contrast detail, it is necessary to distinguish low contrast objects with indefinite outlines against mixed backgrounds. Military air operations are not confined to bright high contrast sunny days, but frequently take place under dull misty conditions and may involve close air support of ground operations. In such operations there is often a requirement to detect targets in which camouflage has been used to conceal sharp contours. An aviator who is able to perform well under such conditions is at a definite advantage, (Ginsberg, 1981).

The technique of measuring contrast sensitivity using sine wave gratings has

steadily gained favour and is now in clinical use to detect peripheral retinal disease, (Arden, 1979). It is a measure of the modulation transfer function of the eye, that is the ability of the eye to perceive contrast at different spatial frequencies - usually in the range 0.2 to 25.0 cycles per degree, the higher spatial frequencies being similar to the range investigated by the Snellen chart. In applying the test the sine wave gratings are produced on a television monitor screen by a grating generator (Fig 4). In short, each spatial frequency to be monitored is presented at zero contrast and the contrast is gradually increased until the candidate is just able to detect the grating pattern which he has previously been shown in high contrast. The test is repeated at different spatial frequencies and a graph plotted of spatial frequency against required contrast for detection. A normal plot of spatial frequency against required contrast is shown in (Fig 5). A simpler form of the test is to use the Arden plates in which the gratings are printed in book form and vary in contrast from the top to the bottom of each page or the Vis-Tech charts.
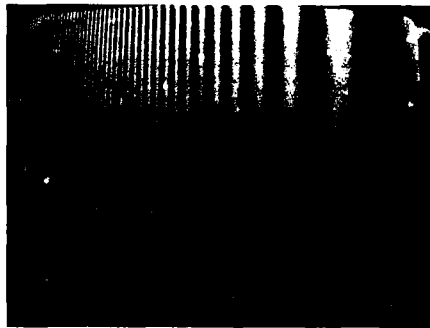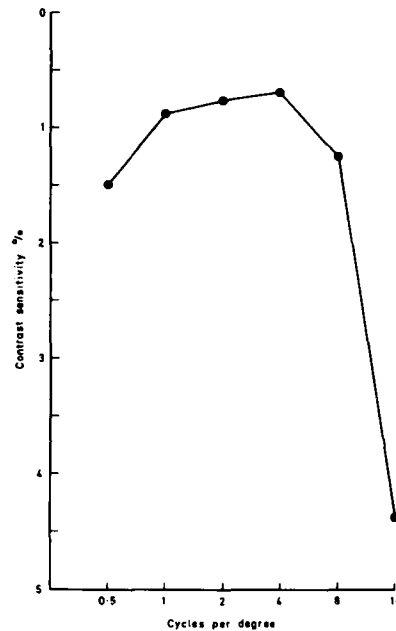

Fig 4. Sine wave grating display with frequency and contrast swept.

Fig 5. A normal plot of ocular modulation transfer function.

Stereopsis

Depth perception is judged by both monocular and binocular cues. The binocular cue of convergence is of little value by virtue of the short base of the ocular range-finder but the binocular cue of stereopsis is considered to be the single most valuable depth cue available to aviators. It is the third stage of binocular visual perception, the two previous stages being simultaneous perception and fusion. The essence of stereopsis is that by virtue of the separation of the two eyes dissimilar images, at points which are non corresponding on the horopter, are present at the two foveae and these images can be fused to produce a three dimensional effect. The difference between the angular subtenses of the target (binocular parallax) as perceived by the right and left eyes is a measure of the binocular parallax disparity (Fig 6). The critical values for detection have been variously estimated at between 2 to 24 seconds of arc, which is very accurate corresponding to a difference of less than the diameter of a single retinal foveal cone. This allows for depth perception out to distances of about 500 metres. The limiting factor is, again, the small inter ocular separation. It is, therefore, of great value to assess the stereoscopic ability of aviators. This is routinely evaluated in many, but not all, countries. The Howard-Dolman or Verhoeff tests are used by the USAF; a minimum discrimination at 25 seconds of arc is required (Tredici, 1985).
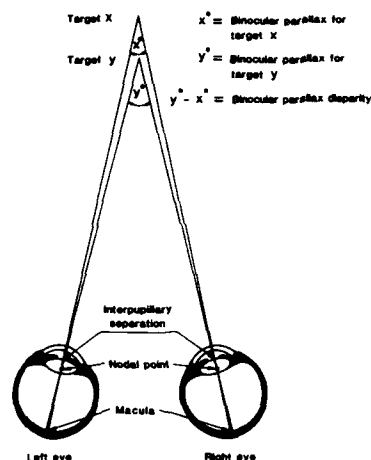
Fig 6. Stereoacuity: derivation of values for binocular parallax disparity.

HAZARDS OF LIGHT

Solar Radiation

Solar radiation, although comprising only a small portion of the electromagnetic spectrum, extends for practical purposes, from the short ultra to the far infra red. It is convenient, as the damage to ocular tissues at threshold levels is wavelength specific, to subdivide the spectrum into the biological bands recommended by the International Commission on Illumination (C.I.E.) (Fig 7).
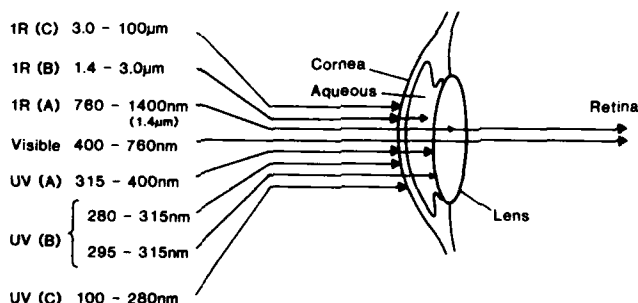

Fig 7. Spectral absorption characteristics of ocular tissues.

Ultra violet (C) extends from 100 - 280 nm and is thus largely absorbed by the upper atmosphere and by nearly all transparent materials. Its activity is confined to external tissues such as skin and the cornea, where due to its very high photon energy it causes tissue death. Fortunately, in aviation, this wavelength band is unlikely to be encountered.

Ultra violet (B) extends from 280 - 315 nm and is again, primarily, absorbed by external tissues where it causes burning of the skin and photochemical effects on the eyes producing, after a latent period, a painful kerato-conjunctivitis which most commonly occurs as 'arc welding eye' or 'snow blindness'. The condition generally resolves with treatment, within 24 hours. Longer wavelength UV(B) (295 - 315 nm) can reach the crystalline lens where it may initiate cataractogenesis. Wavelengths shorter than 320 nm are commonly referred to as the actinic ultra-violet.

Ultra violet (A) 315 - 400 nm, primarily affects the ocular lens where it may cause the delayed (> 10 years) production of cataracts. It is also responsible and used for its ability to cause tanning of the skin.

Visible light 400 - 760 nm. This wavelength band is used for vision with a myriad of hues commencing in the violet and ending in the deep red. Sunlight contains a mixture of all the wavelengths which the eye can perceive. The shorter wavelengths at the blue end of the spectrum are more hazardous to the retina than the longer wavelengths due to the more energetic nature of their photons and to the absorption spectrum of melanin. This gives rise to the 'blue light' hazard which will be discussed later.

Infra Red (A) 760 - 1400 nm (1.4 µm). These wavelengths, like visible light, are refracted by cornea and lens of the eye and may be brought to a focus on the retina. This radiation is not visible and as the retina does not possess pain fibres, over-exposure causing burns is not painful. It is thus capable of causing damage which is neither seen nor felt. In practise the hazards of IR(A) from solar radiation are small, even when using visors or sunglasses which attenuate visible light but do not filter the infra red. Theoretically this situation could produce pupillary dilation by attenuating visible wavelengths and thus allow the unfiltered infra red radiation entering the eye to increase. Eclipse 'burns' are not normally produced by infra red radiation but are caused by the shorter wavelengths at the blue end of the spectrum producing a photochemical solar 'retinitis'.

Infra Red (B) 1.4 - 3.0 µm and Infra Red (C) 3.0 - 100 µm wavelengths cause a sensation of heat and are primarily absorbed by the skin and cornea where painful burns could result. In practice solar radiation burns from infra red do not occur.

Blue Light Hazard

Excessive exposure to the short wavelength component of visible light from solar radiation is an ocular hazard. The blue wavelengths from 400 - 500 nm, particularly those centred at about 440 nm, can cause damage at levels far below those required to produce a retinal burn (Ham et al, 1976). The mechanism is photochemical and affects retinal cones, particularly blue responding cones and, with increasing exposure the retinal pigment epithelium (RPE) also suffers. The RPE acts in a supportive metabolic role to the photoreceptors and if damaged or artificially aged this support may be impaired (Marshall, 1985). This reduction in metabolic support causes an accumulation of waste products within the RPE. These are eventually extruded on to Bruch's membrane; when visible, ophthalmoscopically, these waste products are known as "Drusen". An accumulation of Drusen at the macula can give rise to a senile macular retinopathy and a loss of vision which may progress to a central scotoma. It is possible that, inadequately protected aircrew who are persistently exposed to high levels of blue light may develop macular retinopathies earlier than the remainder of the population.

Visor Tints

Glare protection in fast jets such as the F16 is provided by a tinted visor. The luminous transmittance of the visor should be between 10 - 15% (optical density 1.0 - 0.8). Such a density will attenuate the highest luminances likely to be encountered in aviation (<10^6 cd/m^2) to an acceptable level, whilst at the same time lowering the commonly encountered luminances in Europe (10^4 - 10^5 cd/m^2) to between 10^3 - 10^4 cd/m^2 at the cornea, which is the region in which the eye performs at its optimum. Fixed densities can never, with widely varying external luminances, always provide the correct attenuation of light but an optical density of 0.8 - 1.0 is a reasonable compromise.

The spectral transmittance of the tinted visor is of equal importance to the density. It is imperative that the transmittance of UV(A) and the actinic ultra violet is kept to the minimum and does not exceed 1%. The spectral transmittance in the visible band 500 - 760 nm should be as flat as possible to avoid adverse effects on hue discrimination. To reduce the blue light hazard the transmittance of the shorter wavelengths of the visible band in the spectral domain 400 - 500 nm must never exceed the value for the luminous transmittance and should, preferably, gradually decline from 500 - 400 nm, without any spikes in transmittance. The red signal visibility factor which is the ratio of the transmittances of red and white light should be in the range 0.9 - 1.2 and the violet factor which is a measure of the transmittance of light at 420 nm and 460 nm should not fall below 0.5 (Australian Standard, 1983). These standards should avoid any problems in the perception of red and green/blue warning and advisory lights.

The transmittance in the IR(A) should, ideally, not exceed the value of the luminous transmittance. This is easy to achieve with glass filters, but is difficult to achieve with tinted visors fabricated from polycarbonate or other plastics; it is a long term objective (Fig 8).
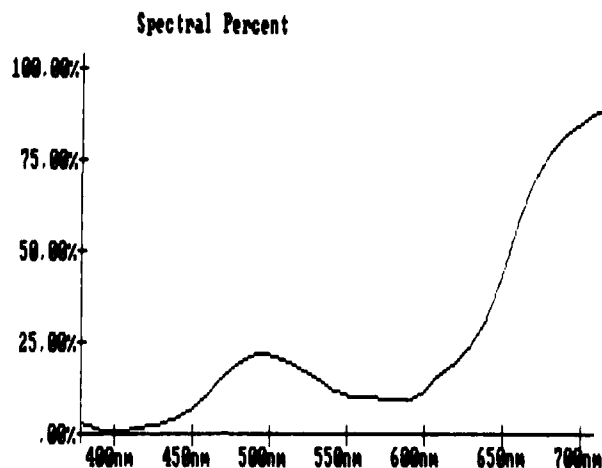
Spectral Percent

Fig 8. An example of an undesirable spectral characteristic in a sun filter intended for use in aviation. Note the rise in transmittance in the deep red and near infra red regions of the spectrum.

Direct glare is caused by a bright light source(s) within the field of view. The magnitude of the visual decrement produced by these source(s) is dependent on the position of the glare source(s) relative to the direction of gaze and to their brightness. Different glare situations encountered in aviation include a pilot looking for a target close to the sun and the glare resulting from reversed light distribution caused by solar reflection from clouds. The solution to direct glare, as previously discussed is the use of tinted visors.

Veiling glare may be defined as the loss of contrast caused by the addition of unwanted light to the visual scene. Scratched or contaminated visors and spectacles will scatter light producing haze, this scattered light may cause the transparency to 'light up', thus significantly degrading vision (Fig 9). A similar effect can be caused by reflections in visors or on the faces of instruments. A particular case in point is that of a pilot whose face is bathed in sunlight. When he directs his gaze to a relatively dark area of his cockpit he may see the defocussed reflection of his face in his visor. This is frequently described as a 'milky' film obscuring his vision. Both haze and reflections must be avoided where possible.
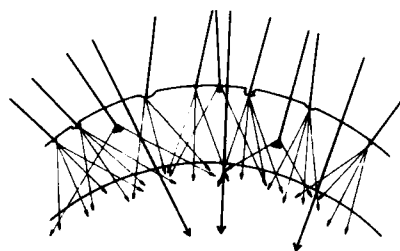

Fig 9. Light scatter in a visor caused by inclusions and abrasions.

Haze can be avoided by care devoted to cleaning and maintenance and by the replacement of visors and spectacles when the haze has risen significantly above the baseline value of 0.5%. The service life of polycarbonate is extended by the application of polysiloxane anti-abrasion coatings. It is important to ensure that any coating procedures do not increase the likelihood of the visor fracturing on impact.

Reflections can be reduced by the application of a quarter wavelength coatings for specific wavelengths in the visible band. If a visor is treated with a coating whose thickness is a quarter the wavelength of light, a reflection from the surface of the visor will be exactly a half of a wavelength out of phase with the reflections from the outer surface of the coating; the two reflections will mutually cancel each other by destructive interference with a consequent gain in light transmittance (Fig 10). Single coatings are usually applied with a thickness corresponding to the peak of the photopic response of the eye (565 nm). It is, of course, possible to apply multiple coatings at selected wavelengths across the visible band. Visors normally reflect approximately 4% per surface, a total of 8%; this can be reduced to approximately 4% by a single coating and to a fraction of 1% by multiple coatings (Fig 11). Multiple coatings are expensive and care is required in cleaning to avoid damage. The optimum and most expensive solution is to apply multiple coatings onto an anti abrasion film.
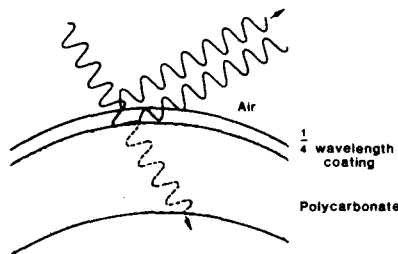
Fig 10. Destructive interference of reflections from the surface of a visor and an anti reflection coating.
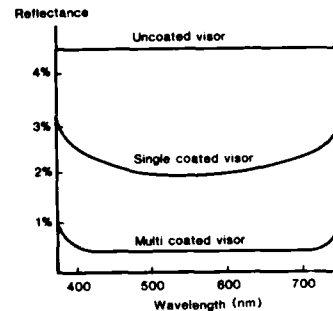
Fig 11. Diagram illustrating the reduction in reflections produced by single and multi anti reflection coatings applied to a visor.

The problem of reflections of instruments and cathode ray tubes (CRT) can also be solved with anti reflection coatings but it may be cheaper to consider other methods. The solutions currently available include, venetian blind type louvre filters which only transmit light in one angular direction, the angle being preset during manufacture. Monochrome CRTs may be made more legible by using special filters which only transmit at the wavelength of the peak emission of the phosphor. Shrouds may also be useful in some instances.

Another form of veiling glare is from scatter sources within the eye (entoptic glare). These scatter sources are usually in the crystalline lens and can significantly degrade vision, particularly in the older pilot. The only solution is to avoid placing older men in a glare situation.

Corrective Eyewear

The shortage of otherwise suitable applicants for pilot training has, in many nations, resulted in a lowering of entry visual standards. When coupled with the development of refractive errors in trained aircrew and the universal incidence of presbyopia in the latter half of the fourth decade, it has resulted in a significant number of aircrew requiring corrective eyewear. In the Royal Air Force it has been estimated that 15% of aircrew, currently, require corrective flight spectacles and this percentage will increase.

Contact lenses do not mist and offer unimpaired integration with optical sights and devices. This led to a trial of soft contact lenses for aircrew. It was decided to use soft lenses with a high water content and good oxygen transfer; as aircrew may be compelled to wear their lenses for periods of up to 48 hours during intensive operations. The subjects were exposed to all the environmental stresses considered relevant in military operations and performed well (Brennan, 1985). There were, however, instances of corneal ulceration and for this reason and that of the difficulty in maintaining sterility of the lenses in the field, contact lenses have not been accepted for general issue to RAF aircrew. The situation is under review

and when new lenses are available with a high oxygen transmissability, ease of
maintenance, user tolerance with extended wear times which also give good visual
acuity; a new trial may be instigated.

Table 1

RELATIVE MERITS OF CORRECTIVE FLYING SPECTACLES
AND CONTACT LENSES FOR AIRCREW

CONTACT LENSES   SPECTACLES

ADVANTAGES

CONTACT LENSES	SPECTACLES
1. Ease of integration with any optical devices such as respirators, night vision goggles, helmet mounted displays and optical sights.	1. Tolerated by all.
	2. Will correct all non-pathological refractive errors.
	3. Wear time unlimited.
2. Lenses cannot mist and provide minor protection against splatter from the firing of the miniature detonating cord (MDC).	4. Provide greater protection against MDC and impact, especially with lens materials fabricated from polycarbonate or CR39.
3. Cosmetically acceptable.	5. Excellent visual acuity generally achievable.
4. Valuable in some eye conditions.	
5. Unimpaired field of view.	6. Can be supplied in bifocal and tinted forms.
	7. Proven in flight.
	8. Easy to don and doff.

DISADVANTAGES

CONTACT LENSES	SPECTACLES
1. Expensive.	1. Integration with some optical equipment can be difficult when eye relief is limited.
2. Not tolerated by all personnel.*	
3. Will not correct all types of refractive error.	2. Dedicated designs may be required for integration with respirators.
4. Some medical conditions permanently or temporarily preclude their use.	3. Will mist under some conditions.
	4. With inadequate frames, field of view may be reduced to an unacceptable extent.
5. Wear time is limited.	
6. Foreign bodies, liquid, gaseous or solid may cause great distress and possible eye damage.	5. Under conditions of extreme vibration may oscillate on face reducing visual acuity.
7. The visual acuity achieved may be variable and in some instances permanently below that with spectacles.	6. Weight.
	7. Robustness and lens integrity may be a problem.
8. Some individuals suffer halation of lights and flare from the edge of lenses.*	
9. Contact lenses may "mould" the cornea so that when they are removed the normal wear corrective spectacles will not restore full visual acuity for some hours.*	
10. Will not provide glare protection or give a reading correction in older aircrew. (New bifocal contact lenses under trial: their suitability for older aircrew will be investigated.)	* These disadvantages are minimised by the use of a high (75%) water content lens.
11. Difficult to maintain in a military environment.	
12. May give rise to serious ocular pathology.	

Table 1 lists some of the advantages and disadvantages of both contact lenses and spectacles and it will be seen that there are problems concerning the field of view and robustness of spectacles. It is vital that corrective flight spectacles be correctly selected. The frames should be made of corrosion resistant, robust, non-allergenic, nationally approved, materials. All joints and screws are to be treated to ensure their integrity under.stress including impact. The fronts and eye shape are to be designed for maximum field of view and compatibility with aircrew protective helmets and oxygen masks. Adequate provision for air circulation to minimise misting must be allowed. The sides should be slim to avoid discomfort from close fitting helmets and be designed to allow easy donning and doffing in flight and to minimise any distortion of ear seals with a consequent loss of sound attenuation. The frame should not deform in use and be free of projections, sharp edges or other features which could impair comfort. The frame should be treated so as to minimise reflections. The frame/lens combination must not degrade under the extremes of ambient temperature (Fig 12).
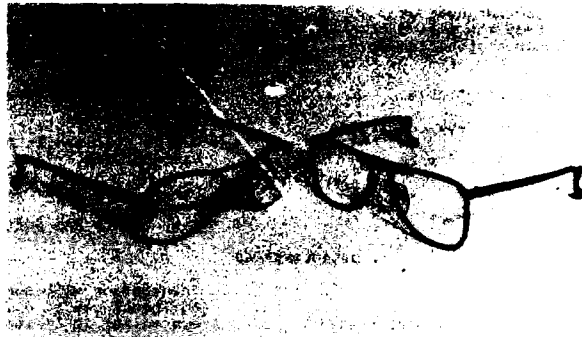

Fig 12. Photograph of the RAF corrective spectacles and respirator spectacles. Note matt black chrome finish and arms designed for comfort and stability when wearing close fitting aircrew protective helmets.

The lenses should, ideally, be fabricated from polycarbonate, due to its un-surpassed impact resistance. Polycarbonate is also light weight, does not transmit ultra violet light below about 380 nm, its refractive index is higher (1.586) than crown glass (1.523) or CR39 resin (1.499), its optical transparency is also good and the lenses can be tinted. Polycarbonate is however soft and requires treatment with conventional anti scratch polysiloxane coatings which may also be combined with anti-reflection coatings. Polycarbonate does possess one major disadvantage in that its Abbé or 'V' factor is low (30) as against CR39 resin (58); this produces a significant dispersion of light in higher powered lenses. It can cause white light to be dispersed into its spectral colours, these colours are not generally noted, but the coloured fringes may reduce the visual acuity of the wearer. For this reason it is advisable to restrict the use of powered polycarbonate lenses to plus or minus 2.0 dioptres which may be entirely spherical or sphero-cylindrical provided the cylinder does not exceed 1.0 dioptre. These values are stringent and may be relaxed in the light of experience. All other powered lenses outside these values, including bifocals, should be fabricated from CR39 resin.

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VISUAL RELATED ACCIDENTS/INCIDENTS

by

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SUMMARY,

Man has evolved as a creature intended to walk on two feet on the surface of the earth, but has acquired the skill to construct machines which enables him to fly. The process has required this basic man to learn, by training, some necessary skills for adapting his sensory system. This sensory adaption is rather fragile and will under situations of stress break down and cause accidents or incidents. This paper discusses, based on accidents/incidents, the different break down modes of man's visual sensory system in the high performance aircraft cockpit.

1.   INTRODUCTION,

You are obviously asking for trouble when you put man into and ask him to control a flying device, high above the earth, at high speeds, under extreme acceleration forces and high stress, anxiety and sometimes fear. Man whos sensory system was designed to keep him oriented and survive on the flat earth under very moderate speeds and negligible accelerations.

When looking at our most primary sensory modality serving spatial orientation, vision, and the systems, procedures and training we designed and developed during the history of flight to make it able t handle this foreign environment, we still recognize distinct areas of conflict. We can keep researching these areas and design new better concepts to solve these conflicts, but we can probably never be completely succesful. But we shall always try.

Two small, well camouflaged aircraft (F-16) in a head-on intercept with high closing velocity collided. In the circumstances there was simply no time to react from visual sighting to collision: .... A very simple rule of accident prevention can be deduced from this accident. Don't design accidents into training procedures, by demanding more from the sensory system than it can physically handle.

2.   Accident/incident data collection,

When investigating accidents and incidents the primary concern is to find the cause or the causes for the accident to have happended. What you have to deduce your findings from, can vary from a lot of material to just a few facts and a form of speculation. You just have those facts, though, you cannot influence the act to get the data you need. This difference from experiments, where you can isolate the specific problem, makes the causefinding very questionable. Which serious investigator has ever been completely sure he has found all the factors or that he has made a totally fair analysis of available data. There always is a certain pressure to find a cause or a probable cause, so the responsible organization can ensure some form of accident prevention. Change the rules, some hardware or methods of training. Most often these changes will do no harm to the safety level but may reduce training standards severely. So are we doing the right thing ? Accidents happen by chance. We must take a statistical or a probability look at accidents. Luckily the odds are against accidents. Especially in small air forces accidents happen so rarely, that it is very questionable to apply statistical significance, and if operational factors are involved, the small air forces are often so unique, that statistics from the major user will not be applicable. Thus, often accidents are not pointing to the most risky behaviour in the air force, it may even be pointing to a real low risk area. Then how do we find these high risk areas ? We have to get much more information on the close calls and even the not so close calls. We must know about the smaller distractions also and not only the complete loss of spatial orientation. We must indoctrinate our pilots an attitude toward complete willingness to and truthfulness in reporting own experiences and behaviour.

It is my belief, that where we deal with break down in pilots sensory capacity, be it under or not under control of the pilots, we have special difficulties in obtaining a true picture from pilot reporting. Our cultures have since the second world war presented young men with a model pilot as an infallible hero, who definitely has the "right stuff". The "right stuff" being in complete control of all sensors at all times and being able to handle any situation through mastery of his

machine and the environment. This hero never experiences spatial disorientation, high load factor disorders or visual illusions. Our pilots have grown up with this role model and have selected their carriers on this basis. He knows of course, that he himself is not flawless or is very early in his training taught this fact. But his version of acquired manhood is in line with this model, and we must realise that he will not very easily report undetected incidents, where his sensory capacity is involved.

We could maybe early in training break down this role model, but it will obviously be difficult if we use the same effect in other respects. And we do. All air forces want highly motivated, selfconscious and aggressive fighter pilots. Some air forces to the point, where pilots constantly are told, that they themselves must believe they are the worlds greatest fighter pilot. On that background it will be difficult, but we must break this safety versus manhood problem. The only way, will be to make it manly to accept your professional shortcomings, to make it masculine to report your own mistakes for others to avoid. We can do this by selecting supervisors, who are individually strong enough to do exactly this, who of-course and without any hesitation will wear his steel helmet:

- In 1917 Colonel Douglas A. MacArthur stated to his aide:
  "I will not appear as a coward to my men by wearing a steel helmet". -

We have come a long way in safety attitudes since then, but there are still miles to walk.

As supervisors and organizations we must be very cautious with the effect of punitive actions in relation to pilot errors. It is very detrimental to openness in accident reporting. The only form of discipline which really works in accident prevention is selfdiscipline and this cannot be enforced, it is a state of mind which is taught, not by punishment, but by rewards.

If it is believed, that general openness is not achievable, a confidential reporting system should be instigated and promoted. Systems can be designed as air force wide Confidential Occurrance Reports or squadron "Hairly Tale" books, but if started, full confidentiality must be strictly ensured.

The bottom line is. If we want to make intelligent safety prevention it is necessary to get a statistical significant picture of the accident/incident mass, so that our prevention actions are not based only on a few spectacular, media interesting, accidents.

3. Visual related accidents/incidents.

As described earlier it is very hard to isolate specific areas in causefindings after accidents, but as vision by far is the most important sen·•· for the pilot, most all accidents in some way are vision related. It is suspected that vision impairment, visual illusions etc. play a much greater role in accidents than the final categorization of cause factors will show. Would we categorize an accident as visual related when the pilot lost spatial orientation caused by looking for a chaff dispenser control switch placed far to the rear on the cockpit console. Had the incident happened at low level, we might not even have a clue about what happened at all. There is no question, though, that the incident happened because the human visual system could not cope with the situation as a whole. This small annoying incident can be approached from different angles:

- Switches, which are to be manipulated during flight should be placed in front of the pilot: Design error.

- The pilot should not manipulate aft switches in IMC turning flight: Pilot error.

- Formation lead should not order change of switch settings to a wingman in IMC radar trail: Supervisory error.

We could probably apply a number of other categories, which would depend on the special interest areas of the time, or of the specific investigator. The correct category could have been physiological incident with most of the others as contributing factors. Prevention efforts must take into account all the mentioned factors and can only be effected if the incident is reported in the first place.

3.1. Focal and ambient vision.

When analysing visual related accidents or accidents for visual contributing factors it is necessary to look for two functionally different systems of vision: Focal vision and ambient vision.

Focal vision is the mode concerned with object recognition and is used to relate data of high detail to the conscious brain or at least to the brain, which hold aquired skills. The brain then processes this data to give a picture of intelligent meaning.

Ambient vision is the mode concerned with spatial orientation and localization. It is not accepting detail but sees at all time the whole picture. It relates to the subconscious not adaptable brain. It acts as the body attitude reference system.

The two types of vision are not only two different processing modes, but uses different physical properties in the eye. The foveal vision and the peripheral vision. E.g. in a high load factor turn with tunnel vision you maintain your focal vision data but looses your ambient vision and the "natural" input to spatial orientation.

3.2. Visual sensory break down modes.

Accidents/incidents indicate several distinctly different possibilities for sensor or processing break down in vision:

3.2.1. Break down of ambient vision/falsely processed ambient input.

Ambient vision will break down if you have no horizon or "landscape" input in clouds, at night, a hazy day over the sea, in a snow storm etc. The aircraft systems are of course designed to overcome loss of ambient vision by using focal instruments (attitude indicator, altimeter etc.) to build situation awareness in instruments flying conditions by a specially trained pilot. Falsely processed ambient inputs can be exemplified by a false horizon made up by a line of lights on the ground, a not horizontal cloud-layer or even a canopy bow. It seems like the ambient system in lack of proper inputs will cling onto anything looking like a straight line. If recognized the effects are overcome by instrument flying skill of the pilot.

3.2.2. Focal vision break down.

Can happen due to extraordinary physical stress factors from high speed, vibrations, altitude and accelerations. All these effects will gradually reduce vision capacity and the effect will normally disappear with the stress.

3.2.3. Processing of focal vision input break down.

This will create what is usually named visual illusions. Visual illusions occur when the visual data either is not recognized or the data is falsely perceived as a well recognized pattern. The effect will most often occur when ambient vision is lost or weak.

3.2.4. Take over by non-suited sensory system.

When inputs from the visual system break down or get weak there is a "natural" tendency for other sensory systems to take control. Especially the vestibular functions, which have very little positive to contribute to flying. These functions will often when supplementing vision be detrimental and create gross errors in spatial orientation.

3.3. Trends in aviation accidents.

The obvious trend in aviation accidents whether looking generally or at one type of aircraft is that accident rates are being reduced overall, but also that the major cause factors gradually shift from technical errors to operational errors. It seems like the advance in technology, which creates the new high performance wonders are followed by likewise advance in reliability. The advance in training of the genetically earthbound man does not seem to be able to follow the same happy path, and we see no reduction in operations error accidents. The trend in operator errors is a shift from general "mistake" errors of overconfidence or complacency to loos of control due to spatial disorientation or g-induces loss of consciousness. I.e. sensor break down. As long as we still want to bring the only wonderful thing about man, his brain, along for the battle, the rest must follow. To break the trend in accidents we have to find new ways to help this genetically unfit body by advancing better training methods and/or devicing some technical means to aid.

3.4. Visual disorders.

3.4.1. Accidents related to vision impairment.

3.4.1.1. Transparencies.

The Flight Manual of the F-16 states, that during heavy rain, water tends to be aerodynamically held to the forward portion of the canopy, obscuring vision as much as 30 degrees back on the canopy. This is true, but how does it affect your flying procedures. A 4 ship formation on recovery in reported good weather, i.e. high cloud base and good visibility with rainshowers. All 4 aircraft experience complete loss of forward visibility at 300 feet and have to go missed approach. All 4 have less fuel than required for diversion to another field. After 3 attempts all 4 aircraft are on the ground, with only scratches on the prides of the pilots, and very short on fuel. All 4 pilots expressed, that the effect had been a total surprise. Their experience ranged from 3500 to 800 hours on different types, but all with more than 500 hours on F-16. They all vaguely remembered the note in the Flight Manual, but all had expected this note to express something they all had experienced often, namely a small degredation in forward visibility. In heavy rain, even with good reported visibility, you can loose forward visibility completely in the F-16.

It is possible to get the same kind of effect much easier. After normal aircraft washdown in connection with scheduled maintenance, it is sprayed with conservation oil. On recovery to landing a pilot enters light rain and experiences that the front and left side of the canopy is completely non-transparant. This conservation oil, wiped off, but not correctly, with light rain, will do this. The pilot finally landed OK, low on fuel, in close formation with another F-16. Luckily he was not alone in the traffic - pattern and really low on fuel.

Helmet visors. Taking off on a late afternoon mission the sun is low and annoying. Everybody are using both the dark and the clear visor. The whole mission is high level intercept training. During the approach and landing phase, one of the pilots experience some difficulties with internal lighting. It is now dark and overcast with a low ceiling. Breaking clouds very low, he has extreme difficulties aquiring the runway lighting. He goes around for a low level GCA and requests the runway and approach lights turned full up. On roll out from a very troublesome landing he realises his dark visor is still down. At the mass-debriefing, there are 10 pilots in the room, he briefes the incident. Two other pilots had had the same experience the same afternoon, although both had realised the visor on short final and removed it. Of the 10 pilots a total of 6 had had the experience at one time. The most important lesson learnt is, that this was the first time it had been reported.

A fairly experienced pilot flies low level in a mountain valley, hears a loud bump and feels a rush of air around him and he is completely blinded. Immediately disoriented and extremely scared he reaches for his ejection handle. Somehow the reflex to reach for the eyes, overpowers the urge to eject. In the process he removes enough birdremains from his visor to be able to see through. Removing the visor he gains complete control and is able to land with a hole in the canopy.

Another pilot has a not quite similar experience. His visors were up and the bird hit his eyes. His remaining vision allowed him to perform a very spectacular and heroic landing in close formation. It was his last landing, though.

3.4.1.2   Physical stress.

Vision will be reduced by a variety of physical stress factors or even lack of inputs. High speed differences between the eye and the object can result in the rapid saccadic eye movement being saturated. The same effect can result from high frequency vibrations of the cockpit or instruments. Lack of inputs by looking into empty space will have the effect that the eyes are focusing very close, so that the one aircraft that is out there is not seen. This has propably caused a number of accidents but the lack of visually aquiring and avoiding an object can have a number of causes, which are impossible to separate. The modern aircraft with head up displays focused at infinity tend to help the pilots to avoid the space-nearsightedness. On the other hand, flying final instrument approach on standard heads down instruments the same effect will tend to force the eyes out of focus, each time the pilot is looking for the runway through the head up display.

The by far most important physical stress factor for vision in the high performance cockpit is from acceleration forces. With the new generation of high performance aircraft the pilot is required to master a completely new flight regime. Maintained performance at very high load factors, well above the level which the human body natural compensatory reflexes can handle. On top of that the new generation fighters have flight control systems which enables very high load factor on-set rates. These high on-set rates have put light to a very serious danger of aviation, g-induced loss of consciousness. The ultimate loss of spatial orientation. A very real killer in high performance aircraft, which should be the subject of a lecture series by itself.

Visual problems in relation to high load factors are the symptoms, which in, before high g on-set rate aircraft, most ofter prevented loss of consciousness. When loosing bloodpressure to the head the first organ to react is the eye. The phenomenen starts with a greying on the visual picture, then narrowing of the field of vision (tunnel vision) progressing to black out, a completely cons-

cious state of blindness and followed often, when g are relaxed by seeing stars. The final state is loss of consciousness.

A pilot descending slightly in a hard turn to a 300 foot base on the air to ground gunnery range saw some approaching birds. In this attempt to avoid these he pulled hard enough to experience complete black-out. In this state he felt a descent and reacted with what he believed was rolling wings level, maintaining load factor and the black-out state. Very shortly thereafter he hit the sea surface, skipped, hit again and ejected out of huge water splash. This accident is a fairly evident case of lost spatial orientation from acceleration vision impairment, but do we know how often this effect has been the descisive contributing factor in other types of accidents. E.g. mid-air collisions during air combat maneuvering.

3.5. Spatial disorders.

It is not well known how pilots aquire the skill to fly on instruments, but most trainees in high performance aircraft experience their extremes in this part of training. On one sortie he feels very comfortable and performs well, and on the next something breaks down his confidence, he becomes a little disoriented and the whole flight is a battle with the instruments. It is a phase of training where elimination is fairly high and sometime you find a very skilled contact student who simply cannot learn instrumentflying. Also you will find examples where the absolute top gun and best tactical pilot in the squadron is the weakest instrument pilot. Alas, you can be the most fine tuned human, having superior vestibular, vision, muscle, tendon and auditory sensors giving input to a "straight A" brain and still not be a good instrument pilot.

Instructor pilots talk about the "natural instrument pilot", when you occasionally find a student who learns and performs well. This student probably has the ability to aquire skills that are exactly the opposite of "natural". It is the skill to use the focal vision to read attitude instruments and in the brain to interprete these to ambient usage. At the same time other "natural" inputs from other sensors must be sufficiently surpresses. The standard attitude instruments seem to be more suitable for this than the head up display system. This is probably due to the fact, that head up displays, for a lot of good rasons, are presenting data 1:1 giving a very narrow and very precise view of a very limited part of the world, which is absolutely contrary to the ambient vision requirements. The attitude indicator is much more ambient in nature, presenting a small but whole world. Some pilots explain they use a dedicated technique, to fight vertigo, in attempting to imagine that the horizon line of the attitude indicator extends further out left and right to impress a full horizon line to the brain. In future cockpits we will see a similar effect implemented by a lasar ray or holographic effect giving the pilot a horizon line to supplement the HUD.

Accident/incident data and interviews with pilots clearly proves, however, that all pilots, the best skilled as well as the less, have experiences of spatial disorientation and visual illusions.

The discussion of spatial disorders will be based on the theory of focal and ambient vision as explained earlier and will be devided into the following parts:

- Visual illusions
- Unrecognized spatial disorientation
- Recognized spatial disorientation
- Disabling disorientation

3.5.1 Visual illusions.

Training manuals for aircrew list and explain a number of optical or geometrical illusions, that will effect flying. All of these, differing runway width, upsloping or downsloping runways and terrain, black hole approaches, white-out effects, visual autokinesis, false horizons etc. will effect the pilots of high performance aircraft, but are not specific high performance problems. They often come from or are strengthened by lack of or false ambient vision inputs. The cockpit of high performance aircraft are characterized by a multitude of different instruments centered in front of the pilot and by a huge three dimensionally curved bubble canopy. The glares and reflections from this combination will always add to these optical illusions. In unfavorable conditions reflected lights from instruments can create impressions of false horizons or the optical quality of the canopy will present false image of runways or approach lights.

Some problems which mostly occur flying the combat mission may come under the headline of visual illussions.

A high speed, very low level into the sun, the pilot flies to pass a mountain ridge well in front of him. Suddenly without visual warning he passes a few feet above another ridge optically hidden by the other, which were a little higher, relative to the pilot line of vision.

On a similar mission the pilot flies a specific altitude not noticing that the terrain is gradually and very slowly sloping uphill. The pilot is very surprised suddenly to find himself only a few feet above the ground.

Two other reported accidents/incidents could be given the head-line : <u>Falsely aquired comfort level</u>. The first pilot passes a coast line just on top of a level cloud layer at 2000 feet. Flies out over the ocean and performs his mission. Returning from his mission he again flies just on top of what he believes is the same cloud formation, and feels very comfortable. Until he suddenly observes the top of 30-40 feet sand dunes at the coast to be above his flightpath. During his mission the clouds have moved and the next layer was surface fog. The second pilot has an engine problem at low to medium altitude and is attempting to correct this problem. He is above a flat cloud layer, which is at about 500 feet. Weather and visibility above is unlimited. He works very comfortably with his engine problem till he descends into clouds and finally ejects just 2-3 seconds before aircraft ground impact. Both these pilots had such a strong feeling of comfort due to a visual environment, which in their subconscious experience should offer safety. They relied on their ambient vision for spatial orientation and were either too busy or too complacent to accept focal inputs.

3.5.2.   Unrecognized spatial disorientation.

From Air Scoop DOCs TURN (Lt. Col. J.D. Stevenson):

> There's a trend developing which the flying safety folks and I have noted in recent mishap reports.   Although it is not new to the aviation world, its persistence is VERY disturbing. It's common to three aircraft mishaps in which I've been personally involved as a flight surgeon.

> An F-111 crew finished its range mission and climbs for home. The aircraft is seen making a gentle level turn near an island at 500 feet AGL. The pilot flew into a dense fog bank and then for no apparent reason, chrashed into the ocean.

> An F-16 pilot goes blind on lead (looses visual), enters the weather and impacts the ground, nose low and fast ... still in the weather.

> An F-111 pilot pulls up for a routine toss delivery enters a cloud, exists nose low and fast, and impacts the ground.

> *The pattern is clear.*

Later in this article Lt. Col. Stevenson writes: "The most fatal characteristics of spatial misorientation is that you don't know it's happening until too late". The final result of any mishap, where a pilot is incapacitated, for whatever reason, is a collision with the ground. We have through the years seen many reports quoting that the aircraft for an undetermined reason collided with the ground. It is a good guess, that in most of these accidents the pilot was flying the aircraft into the ground. Believing until too late, that he was under full control, but in fact suffering from spatial disorientation. There is a by now classic accident, which is repeated again and again. A pilot is pulling off from an air to ground attack and is involuntarily entering clouds. He just wants to pull himself below again and finds himself exiting the clouds too step to recover from dive. We must stop these.

Most all accidents involving unrecognized spatial disorientation occurs when pilots by surprise or at least unprepared enter IMC from VMC. He is not prepared to change his whole sensory priotazion from ambient vision input to focal instrument input, and he continues for too long to hang on to his outdated spatial orientation reference. The classic remedy for this situation is to advice pilots to: "<u>get on the gauges</u>". That will help. If you get on them early enough. When is early enough ? The best answer to that would be: All the time. Try to keep the conscious brain up to date with the spatial position all the time. A better advice would be: "stay on the gauges". The mission type, the weather etc. will determine the cross check rate, but keep a continous cross check of focal instruments. Add to this higher level of awareness a definite and very simple plan for a method to bring your flight path to point UP, from whatever altitude you find yourself. Nose high unusual altitude recovrry methods must of course be understood and trained as well.

Some researchers have a theory that the high performance cockpit presents a new visual trap. The end result is an angle displacement of the visual object. This may come from a physical deformation of the eye under high load factors, resulting in a displaced optical path through the eye, or may be a disorder in coupling sensor inputs under these high stresses. It is not a very common disorder or at least not a very obvious effect to pilots. A small scale interview survey did not result in any positive answers to the question: "Have you experienced a feeling of an object having moved in space from being under high g forces to 1 g flight" ? A couple of mid-air collisions

could be explained by an effect like this, as in both cases a pilot was hit by an aircraft he distinctly claims to have seen moving on a non-collision course. But as earlier discussed deduction of causes and other findings from accident investigation data is questionable.

3.5.3. Recognized spatial disorientation.

In 1986 the Human factors engineering group at General Dynamics conducted a survey on spatial disorientation. The survey was performed by questionnaires filled in by 424 F-16 pilots, all with experiences from other combat types. The basic idea of this survey was to determine whether the F-16 was more conducive to spatial disorientation than other aircraft, and if so, which specific characteristic caused this. The general findings were, I hope to the disappointment of General Dynamics, that the F-16 was no worse or no better than other aircraft. The survey also disclosed that all pilots occasionally experience spatial disorientation, that reflections on the canopy both inside out and outside in are quoted as primary causefactors and that night IMC and especially on the wing is the worst scenario. In this scenario the F-16 was reported to be slightly more conducive to disorientation than other aircraft.

The fact that all pilots experience disorientation indicates clearly that the aquired skill for instrument flying is fragile and can break down for even the most proficient pilot. A pilot will maintain visual dominance over the unwanted vestibular sensations only to a certain point. It is the fragility of this aquired visual dominance, developed through training and maintained through practise that makes spatial disorientation such a hazard.

On recovery from a nightintercept sortie a pair lead attempted to obtain sufficient spacing from his wingman for separate ILS approaches. He therefore descended at high speed into the ILS pattern. The ensuing decelerating decending turn, with anti collision lights on and also extending the landing gear, caused a severe case of spatial disorientation. The pilot recognized his state clearly and reported he had severe vertigo and would climb to VFR on top, which was at about 4500 feet. On top of clouds, VMC, he still felt he was flying inverted. The pilot had a very strong desire to be relieved from his extreme discomfort and was very close to ejecting. Approach control volountered a clearance, that he could descend to VMC below in any direction. This message was caught by the pilot, who, by what he called extreme concentration, managed to descend below, which was at 800 feet. Below clouds the visibility was good and there were lights from a number of small towns, so shortly the problem cleared completely and the pilot made an uneventful landing.

The pilot was flying solely on instruments, when some input caused a break down of spatial orientation. He received strong visual inputs form outside aircraft lighting in clouds and at the same time his instrument lights were turned well down (to avoid refle-). The F-16 anticollision light is a flash type strobe light and the navigation lights were on bright and flashing. This combination of lights with reflections on the F-16 bubble canopy is at night in clouds a very powerful visual impression. The focal inputs were weakened, as the pilot in order to reduce inside out reflections had turned the instrument lights down. Focal visual dominance was weakened so that surpression of other sensory inputs would be questionable. And while in this state, the heavy deceleration in turning flight, the attitude and trim changes from landing gear extension gave strong inputs to the vestibular sensory system. Whether he could have maintained visual dominance it this scenario is doubtful, but the pilot himself has the opinion that the final break down came from the landings lights being on at gear extension. In this incident the pilot was able to control the aircraft to an environment, where he regained enough ambient vision cues to clear the situation. He was so disabled, though, that an IMC recovery would have been impossible, and an attempt may have been fatal. The incident investigation did not reveal any special factors in respect to pilot qualification and fitness. It can with hindsight be said that the pilot with all his actions, asked for it. It is interesting, therefore, that the pilot was totally surprised, that he was not able to "hack" it. His physiological training, the physical part as well as the theoretical must have failed its purpose, when the pilot not only does allow himself into all these traps, but also is surprised in retrospect. What are the lessons learnt in more specific terms:

-   Do not overstimulate vestibular sensors: Simultaneous deceleration, turning and descending.

-   Stimulate the focal vision as much as possible: Turn up the instrument lights as high as comfortable, when flying IFR.

-   Avoid ambient vision stimulation to the extent possible: Turn down outside lights as far as possible. Avoid landing lights in IMC or haze.

-   Avoid stimulating the auditory sensors of a pilot experiencing disorientation: All inputs to a pilot in this situation should be given as orders like: "Level your atti-

tude indicator", "start climbing", "check altimeter" etc. and not in the form of questions.

- Training standards in aviation physiology is less than adequate: Dedicated "vertigo" training should be performed air borne in two seat trainers using vision restriction devices.

A number of other incidents concerning disorientation involves head movements in connection with instrument flying. The maintenance of spatial orientation flying in instrument condition requires a high frequency instrument cross check. Such that a simple interruption of this can give disorientation. If this interruption is caused by looking for something else the head movement through vestibular input will add to the disorientation. In many incidents the need to break the cross check arises from handling an inflight emergency. The remedy for this is clear: The pilots first priority is to fly his airplane. If handling an emergency requires so much attention that the first priority task is compromised, it is time to leave the airplane. The first thing to do after experiencing an in-flight emergency, is to concentrate your instrument cross check, if possible engage the auto-pilot, evaluate carefully the situation by looking, one thing at a time, for fault indications, read the check list one item at a time, then perform the necessary actions on thing at a time. If this train of actions is interrupted, first of all fly the airplane. If the pilot feels that he hasn't got time (i.e. altitude, airspeed etc.) to act like this, it is ejection time.

As also the General Dynamics survey concludes the most inducive flight phase for spatial disorientation is IMC formation flight, especially at night. In this phase of flight the pilot has no vision cues from which to establish his attitude awareness. He looks only at his lead aircraft, in thick clouds and at night maybe only a little part of the lead aircraft is visible. Many pilots experience minor disorientation every time they fly formation im IMC and are completely capable to cope with this. The effect is probably unavoidable, and when it is controllable it must be considered part of the profession. The way to keep it controllable is by very smooth flying of the lead aircraft. When it gets out of hand or the wing pilot becomes so uncomfortable that he is unable to continue, only "lost wingman" procedures can be recommended. A change of lead, which have been seen as a recommended action is very questionable. Change of lead in IMC is a very demanding procedure generally, and should not be performed with a more or less disabled pilot. Most high performance aircraft have very capable auto-pilots. This device, which may not have been designed to the redundancy level of other aircraft systems, can in many cases be the life-safer a disoriented pilot needs. It can be very hard to perform the delicate task of instrument flying on instruments, which all your body senses tell you are wrong, but a pilot may very well have the will power to accept the fact that they are more correct than your body tells you. Then have the auto-pilot fly the aircraft while you sort out your body sensors. For the F-16 is can be recommended to place the auto-pilot control switches in altitude and heading hold. Whenever the auto-pilot master switch is placed to ON, the F-16 will attempt to maintain that altitude and roll to a bank angle of no more than 30 degrees. The combination will ensure that what ever altitude you engage the auto-pilot it will eventually bring the aircraft back to engagement altitude. Provided, of course, that the maneuvering capacity of the auto-pilot is sufficient. If the pilot is completely unable to react initially it will under all circumstances give time.

3.5.4. Disabling disorientation,

Spatial disorientation can be of a nature, where the sensory systems are so strongly affected by opposing inputs, that the pilot is completely disabled. Often by the vision being so blurred that it is impossible to read the instruments or comprehend the natural horizon. Aircraft violent motions, either pilot induced or from mechanical failure can by themselves be so violent that disabling spatial disorientation will occur. A full stick deflection aileron roll at low level caused the pilot to loose control and impact the ground.

A disabling vision related phenomenen should be mentioned. Flicker vertigo. It is described in most litterature, but the occurence is so seldom, that one authority even claims it does not exist. The phenomenen is related to seeing a sharp light source interrupted by a frequency of 8-14 Hz (flicker). The symptoms can vary from complete epileptic seizure to light annoyance.

4. Conclusion.

The high performance aircraft cockpit is a rather hostile environment for man. It introduces him to completely new sensations and put sensory demands on him to which he has no genetic background or tools to handle. He can only meet the demands of this environment if we appreciate the fallibility of his natural orientation system, and from that knowledge device the best instrumentation possible and give him the necessary training and attitude to use them.

VISION THROUGH AIRCRAFT TRANSPARENCIES

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SUMMARY

The primary purpose of this paper is to discuss in detail the optical and visual effects of aircraft transparencies including windscreens, canopies, head-up display (HUD) combiners, and visors. The majority of the paper will treat aircraft windscreens and canopies with primary emphasis on high performance aircraft.

INTRODUCTION

Aircraft windscreens have evolved from relatively small, flat pieces of glass to large, thick, curved, complex, multi-layered plastic structures. This evolution has resulted in windscreens that allow considerable out-of-the-cockpit visibility, provide significantly better birdstrike protection and improved aerodynamics. However, these advances have not come without a cost: the optical quality of the windscreens has suffered. New visual effects have arisen due to the thicker, curved, plastic struc- tures. Each of these has required the development of measurement methods and standards to quantify the effects.

The first section of this paper will describe these optical effects in terms of physical cause, optical appearance, measurement method (both laboratory and field, if appropriate), typical values and possible effects on air crewmember vision. The latter part of the paper will treat helmet visors and HUD combiners and how they integrate with the windscreen. Table 1 lists the optical effects/parameters that are discussed in this paper.

| Table 1. Optical parameters and effects of aircraft windscreens.	
Angular Deviation	Minor Optical Defects
Binocular Disparity	Rainbowing/Birefringence
Distortion	Reflectivity
Haze/Diffraction	Transmissivity
Multiple Imaging	

AIRCRAFT WINDSCREEN OPTICAL PARAMETERS

Angular Deviation

A ray of light passing through a section of transparent material, such as an aircraft windscreen, may be affected in two very separate and distinct ways. Figure 1 is a general example of a ray of light passing through a transparent medium. The light ray is refracted (bent) both as it enters the front surface of the material and as it exits the back surface of the material. The net change may be, as indicated in Figure 1, that the ray undergoes both lateral displacement and angular deviation. Lateral displacement means the ray has been shifted laterally but the exiting ray is parallel to the entering ray. Lateral displacement is usually of little interest in evaluating windscreens because it represents a relatively small (a few centimeters) and fixed effect. Angular deviation, on the other hand, is defined as the change in direction (angle) between the entering ray and the exiting ray. This is much more significant than lateral displacement when considering weapon systems aiming error. The impact of angular deviation on weapon system aiming error is discussed later.

Figure 1. Lateral Displacement and Angular Deviation Effects of Aircraft Transparencies
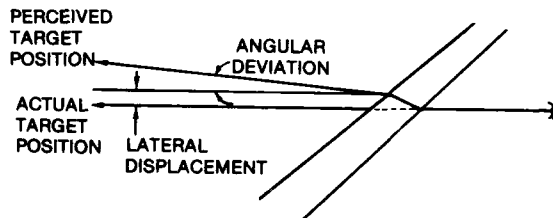
Several methods have been used to measure angular deviation in windscreens for both laboratory research and manufacturing quality control. One of the original methods used for measuring the F-16 windscreen used a laser beam and a long, clear throw distance of

100 ft. The laser beam was positioned at about the design eye position of the wind-
screen and was imaged on a calibration pattern at the end of the 100 ft throw distance.
With no windscreen in the path, the laser beam was imaged on the center of the calibra-
tion pattern. Then, the windscreen was inserted in the path. Any movement of the laser
beam from the center of the calibration pattern was assumed to be due to angular devia-
tion in the windscreen, although in fact at least some of the change in position was due
to lateral displacement. The entire forward section of the windscreen was mapped by
moving (rotating) the windscreen about the design eye position.

A second method was employed which eliminated the need for the long throw distance
and eliminated the error due to lateral displacement contamination of the laser beam
position change. This approach used a collimator and a telescope. The collimator was
placed inside the canopy in line with the design eye position, the telescope was placed
outside the canopy and aimed at the collimator. Inside the collimator was a calibrated
test pattern that was viewed by the telescope. With no windscreen in the way, the
crosshairs of the telescope were lined up with the center of the test pattern. Then, a
windscreen was placed in the path between the telescope and the collimator. Any shift
in the apparent location of the telescope crosshairs, with respect to the center of the
collimated test pattern, was indicative of angular deviation in the windscreen. The
amount of angular deviation was determined by the magnitude of the crosshair shift with
respect to the center of the collimated test pattern. The forward section of the
windscreen could then be mapped by rotating the windscreen about the design eye posi-
tion as in the first method described. This method was superior to the first in that a
smaller room was required for measurement and the measurements were not contaminated by
lateral displacement. However, this method was somewhat time consuming.

The third method that has been employed to measure the angular deviation is
described in detail in AAMRL-TR-81-21. Figure 2 is a sketch of the top view of the
optical system that comprises the third method. Referring to Figure 2 (from left to
right), light from an incandescent lamp is collected by a condensing lens to illuminate
the target plane. The projection lens is located one focal length from the target
plane such that it collimates the image of the target. This portion of the system is
called the transmitter and is located such that the light exiting from it goes through
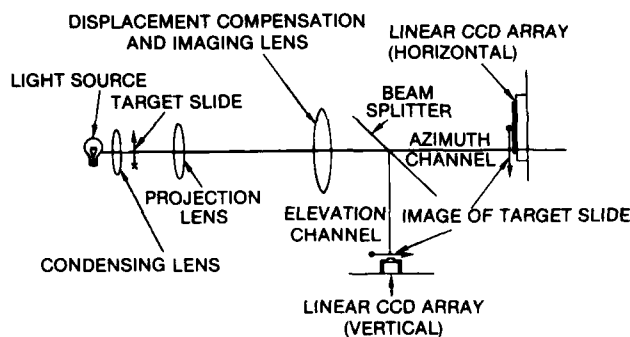the design eye position of the transparency.

Figure 2. Pictorial Layout of Windscreen Angular Deviation Measurement Device
(the windscreen to be measured is positioned between the projection lens
and the displacement compensation lens)

The remainder of the system (the receiver) is located on the other side of the
transparency. The receiving lens compensates for lateral displacement (thus elimi-
nating that source of error) and images the target plane one focal length (of the
receiver lens) away. A beam splitter divides the light into two approximately equal
intensities: one channel to measure azimuth (horizontal) deviation and one to measure
elevation (vertical) deviation. Except for a 90 degree rotation about the optical
axis, both channels are identical. In each channel, a segment of the target image
intersects a charge couple device (CCD) linear array. The positional change of this
intersection between windscreen and no windscreen conditions is mathematically related
to the angular deviation of the windscreen at the point measured.

The target used for this measurement is an "L" shaped pattern. It is important
that the target "L" have uniform width on both the vertical and horizontal segments and
that the segments be accurately perpendicular to each other. The "L" is projected by
the transmitter system and imaged by the receiver lens onto the linear CCD array
elements. The vertical segment of the "L" intersects a horizontally mounted linear CCD
array which measures horizontal or azimuthal angular deviation. Similarly, the
horizontal segment of the "L" falls on the vertically mounted CCD array to measure
vertical or elevational angular deviation.

The elements in the CCD array are typically much smaller than the width of the
image of the "L" segments and, therefore, several CCD elements are activated by the "L"

image. The CCD array control electronics are designed to compensate for this problem. A counter is activated and counts each CCD element until the first element that is covered by the "L" segment is encountered. The counter then counts every other element until the next unactivated CCD element is encountered. Thus, the counter indicates distance from the end of the CCD array to the center of the "L" segment width in units of counts. By knowing the distance between the CCD array elements and the focal length of the receiver lens, it is possible to calculate the angle represented by the counts. In practice, a 10 inch focal length lens can be used in conjunction with a CCD array with 0.001 inch spacing which results in each count representing one-tenth of a milliradian.

This third method of measuring angular deviation is used by a majority of windscreen manufacturers in the USA for F-16 windscreens since it lends itself to direct computer interface, thus reducing the amount of time required to measure a windscreen.

The measurement of angular deviation came about primarily for the F-16 aircraft because of the curvature of the forward section of the windscreen. The visual effect of angular deviation is that the target viewed through the windscreen appears at a different location than it really is. This results in a weapon system aiming error when used in conjunction with a head-up display (HUD). The amount of the aiming error depends on the degree of angular deviation. To correct for this error, each F-16 windscreen is measured and the forward section of the windscreen is mapped. The angular deviation errors are recorded as a function of field angle (look angles). A best fit curve is mathematically determined and the coefficients of the curve fit are affixed to the windscreen as name plate values. These name plate values are then entered into the F-16 fire control computer to correct the HUD aiming reticle for the angular deviation in the specific windscreen installed on the aircraft. Typical aiming errors may range from fractions of a milliradian to several milliradians without this correction procedure. Angular deviation is not easy to measure in windscreens already installed in aircraft and it therefore does not lend itself to field measurement.

Binocular Disparity

There are two distinctly separate phenomena that occur that are commonly referred to as binocular disparity. One of these involves the combination of the windscreen and HUD interaction and is presented in a later section. The second effect is due only to angular deviation in the windscreen. As the pilot looks through a windscreen at a distant object, each eye sees the object through a different portion of the windscreen. If the angular deviation through these two different portions of the windscreen are different, then the image of the object will appear in a slightly different location for each eye. To compensate for this difference, the eye muscles must adjust the orientation of the eyes to cause the image of the object to fall on the appropriate corresponding points of each retina. If the difference in angular deviation between the two areas of the windscreen is too great, the eye muscles cannot shift the eyes sufficiently to compensate and a binocular rivalry condition occurs. The visual system reacts to this binocular rivalry in one of two ways: it either suppresses the image from one eye or the observer sees double.

Binocular disparity is measured by determining the angular deviation from both the left and right eye positions and then subtracting the two measures at each field angle. The errors in the vertical and horizontal directions are treated separately since they have distinctly different effects on vision. In the horizontal direction, the errors translate to vergence of the eyes. If the eyes have to rotate inward (toward the nose) in order to fuse the image of a distant object when viewing through the windscreen, this is called eye convergence. If the eyes must rotate outward, it is referred to as eye divergence. The eyes can tolerate considerable eye convergence but can only tolerate about 2 milliradians of eye divergence. Figures 3 and 4 show typical maps of eye vergence for F-16 windscreens.

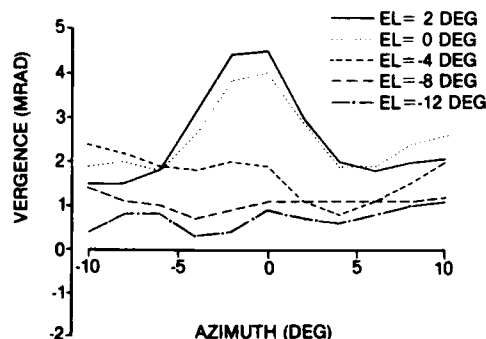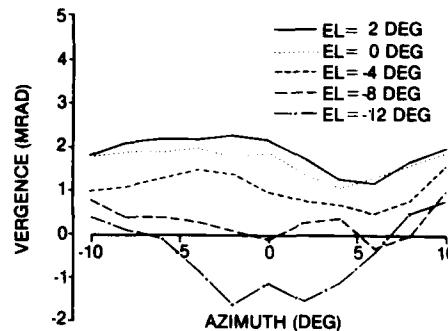Figure 3. Graph of Binocular Vergence (Horizonal Direction) for an F-16 Windscreen

Figure 4. Graph of Binocular
Vergence (Horizonal Direction)
for another F-16 Windscreen

Angular deviation differences between the two eyes in the vertical direction are
called vertical disparity. It is measured by subtracting the vertical (elevation)
angular deviation errors for one eye position from the vertical angular deviation
errors for the other eye. The difference between the two eyes in the vertical direc-
tion is referred to as dipvergence.

Just as in the case of divergence, the eyes have a relatively low tolerance for
discrepencies in vertical position of an image between the two eyes. Typically, about
3 milliradians is the maximum permitted vertical disparity between right and left eyes.

The most accurate measure of binocular disparity is obtained by measuring the
angular deviation of the windscreen from the two eye positions. However, there is an
alternate method of documenting binocular effects that has been relatively recently
promoted. This method uses a twin image projector system (like a slide projector) with
a separation between the projection lenses equivalent to the average distance between
the two eyes. This projection system is positioned at the pilot's head location with
respect to the windscreen to simulate the view from his two eyes. One projector has a
green color filter over it and the other has a red color filter. The projector system
is set about 10 feet from a screen. A rectangular target grid with circles in the
center of each square is projected from each of the eye positions onto the screen.
With no windscreen in the way, the two images of the grid pattern are superimposed to
produce a single yellow image on the screen.

With a windscreen in the path of the twin projector system, each projector will go
through a different portion of the windscreen. Thus, if there is any difference in
lateral displacement and/or angular deviation between the two portions of windscreen,
it will cause a separation of the grid pattern into its red and green components. It
has been suggested that the degree of separation, which can be easily measured, can be
related to the quality of the windscreen.

The difficulty with this method is that the effects of lateral displacement and
angular deviation are both included in the measurement process and cannot be separated.
Thus, the separation between the red and green grids at the screen could be quite
large, but there could be very little binocular disparity caused by angular deviation
in the windscreen. Since, at normal viewing distances through the windscreen, only the
binocular disparity due to angular deviation causes difficulties, the measurement could
provide very misleading results.

The twin projector system can be adapted to field measurement by placing it in the
seat of the aircraft to be tested while the aircraft is in a darkened hangar. A
portable rear projection screen could be set up in front of the aircraft nose and the
image of the twin grid pattern could be photographed from the screen.

Distortion

Over the years, there have been several methods developed to try to characterize
distortion. Almost all of these methods involve photographing a specific type of
pattern through the windscreen followed by an analysis of the photograph to determine
the level of distortion. Unfortunately, distortion in aircraft windscreens is usually
due primarily to manufacturing difficulties. The distortion effects are, therefore,
seldom uniform, symmetric or consistent from windscreen to windscreen and manufacturer
to manufacturer. This makes it all the more difficult to characterize.

By far the most popular method of measuring distortion is based on American
Society for Testing and Materials (ASTM) F 733-81. This test method was primarily
developed for flat or nearly flat transparencies (such as commercial aircraft passenger
windows) but variations of it are widely used for specifying permissible distortion
levels in many other aircraft windscreens such as the B-1, F-16, F-111, F-15, F-18, and
the A-10. This method is commonly referred to as the grid line slope test procedure.

A large pattern consisting of horizontal and vertical lines (about 1/16 inch wide)
spaced typically about one inch apart is the test pattern. Usually, the lines are
white (often made by stretching string) with a black background. The lines are

sufficiently bright that they will show up quite well on photographs. The procedure is to position a camera at a specified distance from the test pattern (15 to 20 feet) and photograph the test pattern with no windscreen in the path. Then, without advancing the film in the camera, a second exposure is made with the windscreen in its installed orientation with respect to the camera such that the camera is in the pilot's eye position. All distortion analysis is then done on an enlarged print of this double exposure photograph.

Grid line slope is determined by inspecting the photograph and determining where the grid lines are sloped the greatest compared to the horizontal and vertical reference lines (the exposure with no windscreen in the path). This slope is usually expressed as a ratio such as 1 in 10 or 1 in 15 (see Figure 5). In practice, the slope can be accurately measured using a digital drafting board which measures the slope as an angle. This angle can then be converted to the traditional ratio by using the following equation:
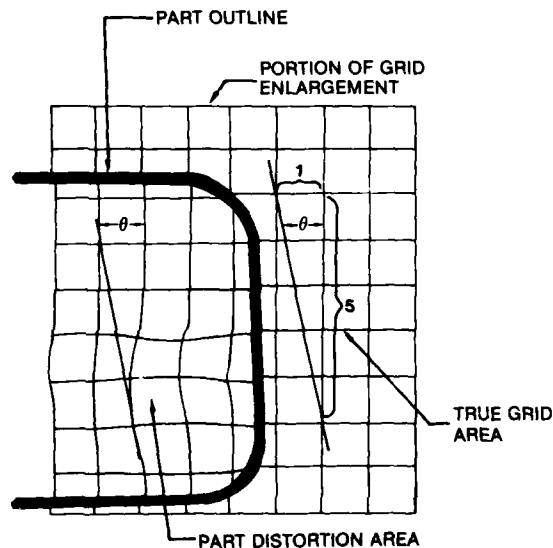
$$GLS = 1 \text{ in } 1/\tan(a) \tag{1}$$

where: GLS = grid line slope
a = angle of grid line with respect to horizontal.

For example, if the slope angle is 5 degrees, the grid line slope would be 1 in 1/tan(5) or 1 in 11.4.

Figure 5. Determination of Grid Line Slope for Assessing Windscreen Distortion

The grid line slope is the maximum slope that can be found in the photograph for the specified area or zone of the windscreen. Typically, the windscreen is divided into zones corresponding to how critical vision is through the particular area of the windscreen. The general area of the windscreen in the straight ahead direction is the most critical and is designated zone 1. Due to manufacturing difficulties, there is also normally an "optical free" zone in which the manufacturer is not held to any distortion specification. The optical free zone is on the order of one to two inches all around the edges of the windscreen. In some aircraft, the optical free zone in the very forward edge of the windscreen may be larger due to the extreme angle that the pilot is viewing through this portion of the windscreen. The extreme viewing angle significantly magnifies optical distortion effects.

A portable system for measuring grid line slope has been developed that permits some level of measuring distortion in the field. A string array mounted on a collapsible frame has been produced that can fit into a modest sized box for easy transport. The strings are spaced two inches apart instead of the customary one inch, but it is apparent from the field distortion measurements that this is sufficient.

Typical specification values for grid line slope are on the order of 1 in 10 to 1 in 16 for critical vision areas (low distortion desired) and about 1 in 6 to 1 in 9 for less critical portions of the windscreen. A value of 1 in 3 has been used for essentially optical free zone areas in an attempt to improve the distortion effects in these areas.

Two other measures of distortion based on the double exposure photographic procedure described above are lens factor and displacement grade. These have been used for a long time in specifying F-111 windscreens, but it is expected that these methods will be phased out in the future pending the outcome of studies to determine if they relate to pilot assessment of distortion.

For lens factor, the enlarged print of the photograph must be made of such a size that the grid board squares (with no windscreen in the way) number 16 per inch on the print. The windscreen is then divided into a relatively complex pattern of zones (NOT the same zone arrangement as described for the grid line slope). Each zone is then inspected (on the photograph) to determine areas in which the squares of the pattern have been compressed or expanded. The number of squares in one inch (on the photograph) are counted for area where it appears compression or expansion has taken place. If the number of squares is less than 16, then the number is divided into 16. If the number of squares in an inch is greater than 16, then 16 is divided into that number. Each of these will result in a number larger than unity indicated some average level of magnification of minification over the one inch areas measured. This number is then cubed (raised to the third power) to spread the numbers out more. This final number is referred to as the lens factor. It is determined for both horizontal and vertical directions and for several zones on the windscreen.

Displacement grade is another measure that is derived from the photographic procedure previously described. With the photograph on a drafting board, a reference horizontal is determined by aligning the drafting edge with one of the horizontal lines that was recorded with no windscreen in the path. Then, the drafting edge is moved about the photograph (keeping it horizontal) in a search for gridlines that show significant displacement over their length. For example, a grid line might gradually rise from left to right from its normal horizontal position. The drafting edge would then be aligned with the left end of the line and the maximum vertical excursion of the line from the drafting edge would be measured (in this example, it would be at the far right hand edge). This distance times 1000 is the displacement grade.

The displacement grade specification is based on a combination of vertical and horizontal displacements using a relatively complex system of zones for the windscreen. The current displacement grade for the F-111 is 120. The portable string board described earlier could be used to measure displacement grade and lens factor in the field but no attempt has yet been made to do so because of the questionable utility of these measures.

Probably the most comprehensive measure of distortion can be made by fully mapping the angular deviation (described earlier) over the entire windscreen. This has been done on a trial basis for F-111 windscreens and is under consideration as a specification that would replace the lens factor and displacement grade specifications. To date, no attempt has been made to convert the angular deviation maps to grid line slope format or other similar reduction of the large amount of data represented by the angular deviation mapping.

It is worthwhile to mention the other methods of measuring distortion that have been tried in the past but that are not currently in use or under consideration for use in specifying windscreens. These include Moiré photography, optical Fourier analysis and the three hole aperture camera methods.

Moiré photography has been demonstrated with aircraft windscreens but no further work has been done to develop this method. The test pattern for this approach is a large square-wave design. In a vertical orientation, this consists of alternating black and white vertical stripes with a width of about 1/4 inch. This pattern is photographed with no windscreen in the viewing path. Without advancing the film, a second exposure is made on top of the first with the windscreen placed in its normal installed orientation. The resulting double photograph shows a Moiré pattern of interference fringes between the windscreen and no windscreen exposures. The number and spacing of these fringes, in general, corresponds to areas of higher distortion in the windscreen. A variation of this method is to produce a double exposure photograph from the two eye positions, thus obtaining a binocular disparity Moiré map of the windscreen.

A closely related technique that uses the same target pattern is the optical Fourier technique (US patent No. 4,299,482). A photograph of the square wave test pattern is produced with the windscreen in position. The film is developed but instead of printing a photograph from the negative, the negative is inserted in an optical Fourier analysis system. The diffraction pattern produced by the negative can be analyzed and has been shown to relate to subjective assessment of distortion in transparent panels (Self & Task, 1980). The disadvantage of this approach is the requirement of a special target pattern and optical Fourier analysis equipment. It is also not being pursued at this time.

An older technique for characterizing distortion is by the use of a three hole aperture in front of the camera. The standard one inch grid board pattern is photographed through the windscreen with the triangularly spaced apertures in front of the camera lens. An enlargement of the photograph was then inspected to determine if the grid lines split anywhere in the photograph. Acceptance criteria was based on the number of splits that were permitted. The technique was based on the assumption that, where the windscreen is distorted, it would also result in a blurred image when photographed with a low number lens. With the three apertures, however, instead of seeing a

blurred grid line in areas of distortion, one would see a splitting of the lines. The intent was to make it simpler to determine acceptance criteria since it is easier to determine if the line splits than if it looks blurry. This procedure is not currently in use with any windscreens and is not being pursued.

Of all the methods to measure distortion, the grid line slope has become the standard. It is not a good measure of distortion but it has survived as the best available method that can be readily used to provide some indication of the level of distortion in a transparency. It is not likely that an alternate procedure will evolve any time in the near future.

Haze/Diffraction

The phenomena of haze in a transparency is actually a manifestation of diffraction. Haze or halation is caused by diffraction of light by either microscopic surface imperfections, such as tiny scratches caused by cleaning, or by the material of the windscreen itself. The diffraction is essentially a scattering of a fraction of the light falling on the windscreen. The amount and distribution of the scattered light depends on what is causing the scattering, the intensity of the incident light, and the geometry of the viewing angle through the transparency. The effect is the appearance of a haze or veiling luminance that reduces the contrast of objects viewed through the windscreen.

Haze in new windscreens is relatively low and in glass windscreens is almost nonexistent. However, as plastic windscreens are repeatedly cleaned, even following recommended cleaning procedures, tiny micro-scratches are created on the surface. These micro-scratches act as diffraction gratings with random line orientation and spacing. The result is a scattering of light the appears as a haze. As the windscreen is cleaned more and more, the number of these scratches increases until the scattered light problem becomes severe enough that it is difficult to view through the windscreen under some illumination conditions. The worst viewing condition is in directions close to bright sources of light, such as the sun. The scattering of light is not uniform, but rather is much worse for small angles close to the source of the light. In general, the amount of scattered light decreases with the square of the angle between the line of sight and the light source.

The standard method of measuring haze is ASTM D 1003-16, which is based on a method developed by the National Bureau of Standards. This method is depicted in Figure 6. An incandescent, collimated light source directs a beam of light through a test area into an aperture in an integrating sphere. The beam is so aligned that it also exits the integrating sphere through an aperture at the opposite side of the sphere. The area between the beam source and the entrance to the integrating sphere is where the test specimen is placed. A photodetector in the integrating sphere measures the average amount of light bouncing around inside the sphere. With no sample in the way, the readout is adjusted to read zero. A reference plate, internal to the integrating sphere, is then positioned so as to cover the exit aperture of the sphere. The beam of light is then fully scattered within the sphere. With the reference plate in position, the sample is placed in the test area and the photodiode reading is adjusted to 100. This reading corresponds to the fact that all the light getting through the sample is collected and averaged by the sphere, but the scattered transmitted light has not yet been differentiated from the unscattered transmitted light.

NBS HAZE MEASUREMENT
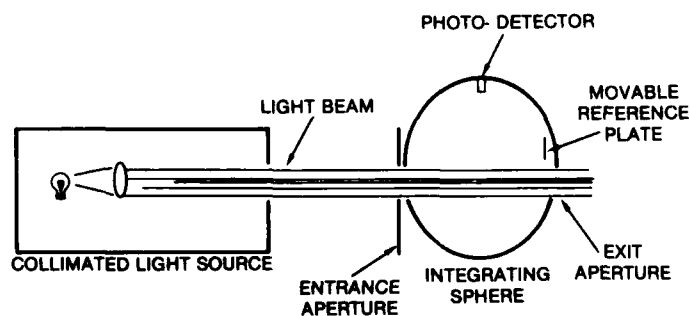
Figure 6. Instrumentation Measuring Haze Using ASTM D 1003-61 Test Method

Without changing any settings, the reference plate is removed from the exit aperture of the integrating sphere. If the test sample does not scatter light at all, then the entire beam exiting the sample and entering the sphere will exit through the exit aperture of the sphere. However, if the sample scatters some of the light, thus changing its direction, it will not pass through the exit aperture. The photodetector will then measure the average fraction of the light which enters the integrating sphere

but does not exit the sphere. This fraction is read out directly on the display. In equation form:

$$H = \frac{S}{T + S} \times 100 \text{ \%} \qquad (2)$$

where: H = Haze in percent
S = Scattered light (that passes through the sample)
T = Transmitted light (only the unscattered transmitted light)

Commercially available instruments have been developed which can make this measurement very accurately. It is by far the most often used method to specify haze. However, it does have a significant drawback: it is difficult to use on other than small samples and virtually impossible to use on windscreens already installed on aircraft. Thus, while it is useful for specifying new parts, it is not useful for determining when a windscreen should be removed from an aircraft in the field because of too much haze.

In an attempt to develop a field usable method, an alternate approach to measuring haze has been devised and published as ASTM F 943-85. This approach has been applied to A-10 and F-16 windscreens with some success (Task & Genco, 1985), however, it is difficult to apply without suitable training and is probably not appropriate for routine (non-research) use.

This test method is based more on the effects of the haze on human visual capability. As light falls on the transparency it is absorbed, reflected, scattered or transmitted unaffected. For a fixed transparency and illumination angle, the amount of scattered light is directly proportional to the illumination falling on the surface. If the amount of incident illumination is doubled, then the amount of scattered illumination is doubled. Thus, the important factor is the ratio of the scattered light to the incident light. In equation form:

$$H_i = \frac{L}{E} \qquad (3)$$

where: H_i = Haze index
L = veiling luminance caused by scattered light
E = illumination falling on windscreen surface.

The haze index is in units of luminance/illuminance such as foot-Lamberts per foot-candle. It should be noted that the haze value is highly dependent on the geometry of the illuminating source and the angle of view through the transparency. This may at first seem to be a disadvantage of this method compared to the nondirectional ASTM D 1003-61 test method. However, it does directly relate to the observed visibility through the transparency, which also varies with illuminating and viewing geometry.

The haze index can be measured both in the laboratory and in the field using similar techniques. For laboratory measurement, a semi-collimated light source is used to illuminate the transparency to be measured. A photometer is positioned at the design eye location of the windscreen to measure the amount of veiling luminance produced by the illuminating source. A black, light absorbing surface must be placed in the line of measurement to insure that the luminance being measured is only the scattered light and not a combination of scattered and transmitted light (see Figure 7).

Figure 7. Haze Measurement Procedure Using ASTM F 773-81 Test Method
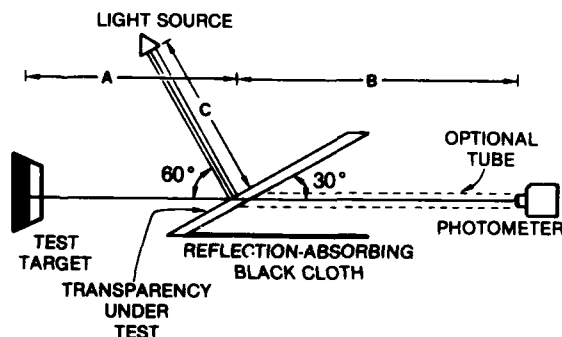
The illumination falling on the surface of the transparency can be measured using the same photometer by making use of a Lambertian reflector. A Lambertian reflector is a surface that reflectively scatters all incident light in a perfectly diffusing fashion. Because of the way in which foot-candles (illumination) and foot-Lamberts (luminance) are defined, the luminance of a perfectly diffusing reflector in foot-

Lamberts is numerically equal to the illuminance in foot-candles falling on the surface. Thus, one can place a near Lambertian reflector (such as a flat white, Barium Sulphate plate) on the surface of interest and measure its luminance in foot-Lamberts. This value is numerically equal to the illumination falling on the surface in foot-candles. Once the veiling luminance and incident illumination are measured, the haze index can be calculated using Equation 3. To fully characterize the transparency, the haze index should be measured for all illuminating and viewing angles of interest.

The haze index can be measured on installed aircraft transparencies in a manner similar to that used in the laboratory with some modifications. Instead of using an artificial light source, one can use actual sunlight if the sun is oriented correctly for the desired measurement. Under field conditions, the black area of the black and white test pattern will probably not trap all of the light; it will reflect some light which may be enough that it needs to be accounted for when measuring the haze index. This is done by modifying Equation 3 slightly to compensate for the light that may be reflecting from the black target area. The modified equation is:

$$H_i = \frac{L - Bt}{E} \qquad (4)$$

Where: B = luminance of the black area viewed directly
t = transmission coefficient of the windscreen

It is possible to relate the haze index value to the amount of contrast loss that would be experienced by a pilot viewing through the transparency. Equation 5 describes the amount of contrast loss as a function of the haze index, transmission coefficient and the ambient illumination conditions:

$$CL = 1 - \frac{M}{M + EH_i/t} \qquad (5)$$

where: CL = fraction of contrast loss
M = Mean (average) target luminance
E = illumination on the windscreen
H_i = haze index
t = transmission coefficient of the windscreen

There are many families of curves that can be graphed based on Equation 5 that show the effects of the different ambient conditions and windscreen haze index on amount of contrast loss. It should be used in Equation 5 that the haze index appears in conjunction with the transmission coefficient of the windscreen. For this reason, the quantity H_i/t has been designated the haze ratio which is the critical quantity for comparison between windscreens. Table 2 is a summary of some haze index and haze ratio measurements that have been made for several aircraft along with pilot comments regarding the windscreens.

Table 2. Typical values of haze index and haze ratios for windscreens.

TRANSPARENCY	HAZE INDEX *	HAZE RATIO *	COMMENTS
F-111 Glass W/S	0.005	0.011	Good
F-111 Plastic W/S	0.040	0.080	Marginal
LANTIRN HUD Eyebrow	0.045	0.085	Marginal
LANTIRN HUD Center	0.013	0.020	Good
F-16 W/S (Plastic)	0.023	0.035	OK
F-16 W/S and LANTIRN			
HUD - Eyebrow	0.048	0.150	Poor
HUD - Center	0.033	0.078	Marginal
A-10 Plastic W/S	0.022	0.030	OK
A-10 W/Residue	0.110	0.158+	Unacceptable
A-10 W/S and HUD	0.042	0.080	Poor

* Units are ft-Lamberts/ft-candle

These data were taken at different times on different efforts for different reasons, so it is somewhat difficult to establish exact guidelines from this table. However, it is apparent that the windscreens become unacceptable somewhere in the neighborhood of about 0.16 ft-Lamberts/ft-candle of haze ratio.

A further advantage of this haze index approach to measuring halation in windscreens is that Equation 5 can be combined with basic vision data concerning the effects of contrast on performance to calculate the effects of the haze on pilot detection performance.

A third method of characterizing windscreen haze is currently under development. This method makes use of the fact that some of the scattered light from the windscreen is scattered back toward the direction of the illuminating source. If this rearward scattered light can be separated from the reflected light and measured, it would be possible to use it as a measure of haze in the windscreen. A prototype device using

this approach has been designed, built and tested. The device worked reasonably well with new transparent parts where the scattering was primarily internal to the material as opposed to being caused by surface scratches. However, when the device was used to measure old windscreens, the linear micro-scratches on the surface of the windscreen produced a diffraction pattern that was not circularly symmetric. Since the prototype device sampled only a portion of the backscattered light in one direction, it did not produce reliable nor repeatable readings. Figure 8 shows the prototype device (US Patent No. 4,687,338).
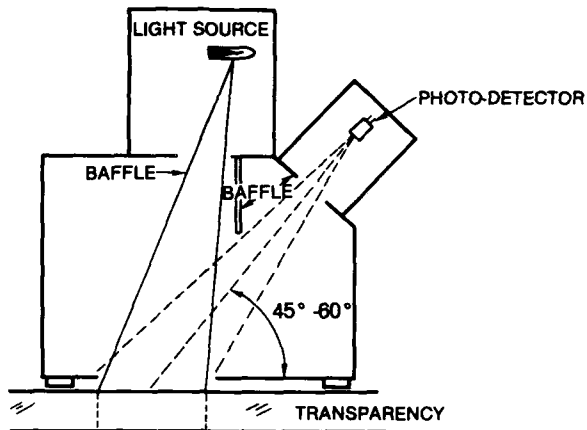

Figure 8.   Diagram of Prototype Device to Measure Haze Making Use of the Backscattered Light

In order to correct this problem, an alternate design approach has been developed. This approach uses an integrating sphere to capture and average all of the back-scattered light while providing sufficiently large apertures to permit the reflected light to escape from the sphere. This device is in the process of being fabricated and tested. The intent is to produce a device that can be easily used in the field to permit measurement of windscreen haze by minimally trained personnel. This would provide a quantitative means of determining when the windscreen should be removed from the aircraft due to haze.

Multiple Imaging

Multiple imaging is typically only visible (and only a problem) during night flight, particularly night landings. Light from external sources, such as runway marker lights and the glide slope indicator lights, are seen both directly through the windscreen and as a secondary, and sometimes tertiary, image. The secondary image is caused by the light from the source coming through the outer surface of the windscreen, being partially reflected by the inside surface (surface closest to the pilot), then partially reflecting again from the outer surface and finally going to the pilot's eye (see Figure 9). The effect of this is to present two images of external light sources to the pilot. The position of the secondary and the intensity of the secondary images with respect to the primary, varies considerably depending on the parallelism of the inner and outer surfaces of the transparency and the angle of view through the windscreen.
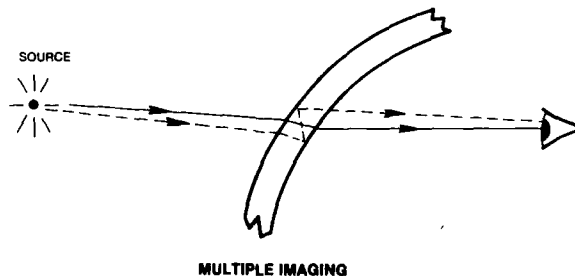

MULTIPLE IMAGING

Figure 9.   Ray Trace Showing the Reflections That Cause Multiple Imaging

There are two parameters of interest with regards to multiple imaging: the ratio of the intensity of the secondary image to the primary image, and the apparent angular separation between the secondary and the primary. A test procedure has been developed

for each of these parameters. The test procedure to measure the angular separation between primary and secondary images is in the process of being accepted as a standard ASTM test procedure. It should be fully approved by late 1988.

The angular separation between primary and secondary images is determined by photographing a rectangular array of lights spaced about 16 inches apart and positioned about 23 feet from the design eye position of the windscreen. At this distance, the angular separation between the lights is approximately 3.3 degrees. On the photograph, the distance between the lights is measured in linear units. This provides a conversion factor to convert between distances on the photograph and angular distances from the design eye position. For example, if the separation on the photograph between the primary images of two adjacent lights is 20 mm, then one can convert from mm on the photograph to degrees of angular subtense by multiplying the photograph distance by 3.3 degrees/20 mm or 0.166 degrees/mm. Then, a digital caliper can be used to measure the linear distances between the primary and secondary images on the photograph. These linear distances can then be changed to angular separations by using the conversion factor. From our limited experience so far with this metric, it appears that the pilots are reacting primarily to the angular separation between the primary and secondary images in the lower portion of the windscreen. This makes sense in that this area of the windscreen is the most critical during landings and the intensity of the secondary images is also the greatest in this area.

The intensity ratio between the secondary and primary images is measured using a custom designed incandescent point source projector. The device is just like a slide projector with the slide being an opaque sheet with a tiny pinhole in it. The projector is positioned about 15 feet from the windscreen and the image of the pinhole is focused through the windscreen at the design eye position of the windscreen. A secondary image of the point source also appears near the design eye position due to the multiple imaging effect in the windscreen. Typically, this secondary image is separated from the primary by a small distance due to the lateral displacement effect of the windscreen. The intensity of the primary and secondary images is measured using a photometer configured to measure illumination. The active area of the photometer must be sufficient to include all of the light (separately) in the secondary and the primary images. This typically corresponds to a circle of light about one centimeter in diameter. The intensity ratio is calculated by dividing the illumination in the secondary image by the illumination in the primary image. This value is calculated for all field angles of interest.

Minor Optical Defects

Minor optical defects refer primarily to small inclusions in the windscreen or small bubbles. The inclusions may be tiny bits of dirt or other impurities or even pieces of hair. Typically, most minor optical defects are not visible except under close visual inspection. Specifications for minor optical defects limit the number and size of defects that are permitted. Inspectors locate and optically measure the diameter of each defect that they can find. This is typically a time consuming and laborious process, but is a requirement as part of the acceptance test procedures for all new windscreens.

Most minor optical defects are probably not even noticed by aircrew members. At least one study (Kama & Genco, 1982) was done to look at the effects of minor optical defects on subject target detection performance. The results of this study indicated that specifications for minor optical defects should probably be relaxed since the size and density of defects investigated (which far exceeded the acceptance criteria) showed no loss in target detection performance. However, specification requirements have not been relaxed.

Rainbowing/Birefringence

Birefringence is a phenomenon that occurs with polycarbonate under stress. Stress causes the material to exhibit two indices of refraction depending on the polarization state of the incident light. The details are far too complex to cover here, but the result is that the windscreen may appear to have a pastel rainbow effect in some areas for clear sky conditions. Sky light can be as much as 80% polarized during a clear, blue sky day. This effect has been noted on all plastic aircraft windscreens. As yet, there is no procedure for quantifying the severity of the rainbowing pattern so it is usually not specified. The color pattern seen is usually due to unrelieved stress in the windscreen that occurs as part of the manufacturing process. Efforts to reduce this effect have not been very successful.

Although the rainbowing pattern may be easily visible, it is usually not considered to be a significant problem by aircrew members. The spatial pattern of the rainbowing remains fixed, but the colors that make up the pattern shift as the aircraft changes orientation with respect to the partially polarized skylight. It has been hypothesized that this swirling of the colors might cause a distraction, however, there has been no evidence to indicate that birefringence or rainbowing is a significant problem. Pilots wearing (unauthorized) polarized sunglasses would see this effect greatly exaggerated.

Reflectivity

Reflections occur at the interface between any two transparent media that have unequal indices of refraction. Thus, there is a significant reflection at the air/windscreen interface since the index of refraction of air is almost unity and the index of refraction of the plastic windscreen is typically on the order of 1.49 or 1.59. It should be noted that the reflectivity at the inside and outside surfaces of the windscreen is the basis for multiple imaging discussed earlier.

Reflections are of concern for several reasons: first, it is the basis for the multiple imaging problem; second, it causes a loss of contrast for daytime flight due to reflections of the glare shield in the windscreen; third, it is a source of distraction during daytime flight due to the reflection of the pilot's helmet in the windscreen; and fourth, reflections of internal cockpit lights during night flight are an annoyance.

There is no practical method as yet to reduce reflections on aircraft windscreens. All antireflection techniques are either too delicate for windscreen use or are wavelength and angle dependent, making them unsuitable for aircraft use. However, with the increased interest in reducing glint (also caused by reflection from the windscreen) and other unwanted reflections, there has been a draft ASTM test method to measure the reflection coefficient. Although not yet approved, it is expected that this test procedure will be validated before the end of 1988.

Transmissivity

As noted above, some light is reflected from the surface of the transparency. Additionally, some light is absorbed by the windscreen material and some light is scattered. The remaining light is transmitted through the transparency and is usable for viewing the outside world. The transmission coefficient is the ratio of the transmitted light to the total incident light.

The present method of measuring transmissivity is based on ASTM D 1003-61 which uses an integrating sphere approach to the measurement. This method can only be used on relatively small samples (or coupons) of material and is designed to make measurements of transmissivity essentially perpendicular to the surface of the coupon. In addition, this method measures luminous transmittance which includes both scattered and unscattered transmitted light (only the unscattered transmitted light is useful for producing in image). Despite these shortcomings, this method is the standard method used for specifying transmissivity in aircraft windscreens and aircrew visors.

Since the reflectivity of the surface varies with angle, the amount of light transmitted also varies with angle. Thus, a measurement of transmissivity perpendicular to the surface of a material does not provide a good measure of the transmissivity apparent to the pilot viewing through the windscreen. For this reason, an alternate transmissivity measurement procedure is under development. This procedure requires a light emitting surface and a photometer. The luminance of the light emitting surface is measured both directly and through the windscreen. The ratio of the two readings is a measure of the windscreen transmissivity. Since the windscreen does not have to be mounted in any special orientation nor put in contact with an entrance aperture, it is possible to map the transmissivity of the entire windscreen as seen from the pilot's eye position. This can produce significantly different numbers than the currently accepted standard method. For example, the transmissivity of the B-1 windscreen using the standard, perpendicular method is about 65%. However, the actual transmissivity through the nose region of the B-1 (about 82 degrees angle of incidence) is closer to about 20%.

Field measurement of transmissivity is not possible using the ASTM D 1003-61 method but is relatively easy using the photometer and light source method. However, care should be taken when using the photometer and light source method to minimize sources of error. The windscreen should be shaded from direct light sources to prevent haze from confounding the reading and a black light absorbing surface should be used to cover the glare shield to minimize reflections from this source. Either of these problems will tend to result in a higher reading of transmissivity than actually exists.

It is difficult to accurately quantify the effect of transmissivity on aircrew performance. A lower transmissivity does not decrease contrast but it does decrease the apparent brightness of objects viewed through the windscreen. A lower luminance level, in general, will result in a lower visual acuity of the pilot. This effect is probably not significant for most daytime flying conditions. Only on severely overcast days or during twilight would a loss of visual acuity due to lower windscreen transmissivity probably be measurable.

WINDSCREEN, VISOR, AND HUD INTEGRATION ISSUES

Many of the same characteristics and measurements can be applied to visors and HUD combiners as well as windscreens. Angular deviation, distortion, minor optical defects, haze, transmissivity and reflectivity all apply equally well to visors and HUD combiners. Of particular interest are angular deviation, haze and transmissivity. Since the pilot must view through all three transparencies (the visor, HUD combiner and windscreen), the effects of angular deviation, haze and transmissivity of each of these transparencies can combine to produce larger overall effects on vision.

Normally, angular deviation measurements are not made on visors. Instead, visors are typically characterized by the amount of prismatic deviation, spherical power and cylindrical power in the visor at different locations on the visor. If the visor deviations and the windscreen deviations happen to be in the same direction, the overall effect of viewing through the visor and windscreen together could produce visual problems.

Haze effects tend ɔ reduce contrast of objects viewed through the transparency. Typically, visors have very low haze values (less than 1%) as measured using the ASTM D1003-61 test method. However, as visors age and are used, they get scratched and pitted thus increasing their haze effects much the same as the windscreens. Add to this increased haze in the HUD combiner due to dust or poor cleaning practices and the overall loss of contrast through the combination of visor, HUD combiner and windscreen can be very great for some viewing conditions. Contrast loss in excess of 90% has been measured for some aircraft windscreens and viewing conditions.

Since transmissivity (t) is a mulitiplicative parameter, the amount of light that actually gets to the pilot's eyes depends on the product of the transmissivities of the visor, HUD combiner and windscreen (as well as the pilot's glasses, if worn). For example, if the pilot is wearing the clear visor (t=.92) and has a conventional HUD combiner (t=.5) and is viewing straight ahead through the F-16 solar coating windscreen (t=.65), then the total transmissivity would be: t=(.92)x(.5)x(.65)=0.30 or about 30%. For daylight conditions, this loss of luminance should not be a problem at all. However, during dusk and dawn and on heavily overcast days, this 30% transmissivity will tend to reduce the pilot's visual acuity by some small but measurable amount.

Another area of concern for HUD/windscreen integration has to do with the optical distance at which the HUD symbology appears. HUDs are normally set so that the image produced by the HUD appears to be at optical infinity. That is, the eyes are looking straight ahead and are focused at infinity (or close to it). For the F-16, the forward portion of the canopy acts like a slight negative lens. This causes objects that are actually very far away to appear to be about 100 to 150 ft away in terms of eye convergence and focus. Since the HUD was designed to produce essentially a flat field at infinity, a mismatch occurs between the apparent optical distance of objects viewed through the windscreen and the apparent optical distance of the HUD symbology. This mismatch, at a minimum, causes an aiming error due to parallax (which is partially corrected by the angular deviation mapping and HUD symbology correction). At its worst, it could cause a pilot to see two targets and one aiming reticle (where there is only one target) or two aiming reticles and one target.

This condition has been somewhat corrected by decollimating the HUD image so that it appears at about the same optical distance as the object viewed through the windscreen. Since these corrective actions have been taken, there have been no further complaints about seeing double.

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GENERAL OPERATIONAL AND TRAINING VISUAL CONCERNS

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SUMMARY

After having stated all the requirements for man-machine interface in
modern cockpit, taking into account all the operational requirements, and
also the physiological and environnemental constraints, the emphasis is
put on visual displays, more precisely on the HUD. How they are realized,
the informations which are presented to the pilot and the physiological
problems encountered are discussed such as: effects of "G" and vertigo.
For the latter, the most often cited causes of vertigo are studied.
New systems are also cited such as Helmet Mounted Display (HMD) or Night
Vision Goggles (NVG). Both are still under development.
We also address the need for simulators and the physiological problems
associated with their use.

1 INTRODUCTION

The purpose of this introduction is to outline the complex requirements
for an human operator on board a fighter aircraft. Man has a physical size and
weight and needs space to work in and lines of vision to observe pertinent
outside actions or surroundings, and pilots come in all shapes and sizes. Within
anthropometric ranges, he will have to fly the aircraft, to reach controls and
to see the displays. One of the most important constraints is to give the pilot
the possibility to sustain high "G's", because modern aircraft, with the
extensive use of fly-by-wire technologies associated with powerful engines, do
have the possibility to reach and maintain high "G's". Raising the height of the
rudder pedals on fighter aircraft makes not only that the blood circulatory
system has an easier task but also that pedal movements are more easily made.
The basic answer to that requirement is thus to tilt the seat, as shown in FIG.
1. It can be seen however that a tilt up to 60 degrees has almost no benefit for
sustained "G's". But the reclined position makes that the pilot will accept
higher "G" onsets, which occur so often on modern aircraft. It is a well
established fact that a man in supine position is better able to tolerate "G"
than a man in upright position. But unfortunately, the supine man cannot operate
an aircraft in good conditions. He cannot see where he is going, he has poor
lateral sensitivity and poor lateral vision. That means that his ability to
manipulate and control an aircraft is greately reduced compared to the seated
one. FIG. 2 illustrates this fact.
As a proportion of the total flight time the pilot spends at high "G" is small,
no compromise is allowable in case of operations at 1"G" (T/O,cruise,LDG) in
order to achieve better performances under "G's". Therefore, a reclined position
must be looked at which gives some benefit (in terms of "G") with limited
adverse effect in other flight regimes.
On the other hand, as the seat tilts, the visibility of side panels will become
more difficult, and the front panel area will be reduced, as shown in FIG.3.
This loss in front panel area as the seat is tilted is not too critical, because
simple electronic displays are already in use in the aircraft (as indicators or
alphanumeric status devices) as shown in this advanced cockpit layout.(FIG.4)
Other requirements are also to be considered in the design of the cockpit, such
as the need for an easy entry and exit of the pilot, or for the ejection from
the aircraft in flight. The design criteria for safe ejection, including
jettison of the canopy, use of leg restraints, knee clearance of stick, panels
and coamings are existing under the form of Military Specifications.
All the constraints have to be considered, but for the preliminary design of the
cockpit, which must be done as soon as possible to reduce costs, the primary
role of the aircraft is the most important consideration. Let us consider two
roles, which lead to almost opposite requirements: the air combat role and the
ground attack role. For the air combat role, the aircraft is used against
manoeuvring target and will meet its opponent by radar vectoring from the

ground, or by independant search and steering. After an initial pass, if
unsuccessful, a dogfight can develop, at low or medium altitude. High supersonic
speed is not required, but the best possible sustained and instantaneous turning
performance is essential. The cockpit must be designed for "G" tolerance of the
pilot, which requires a reclined seat, but also a good outside field of view is
of prime importance in combat, particularly in the rear quadrant, which requires
a more upright position. That means that a compromise must be done.

Considering the second role, for ground attack, the aircraft is operating
primarily at low altitude, with less emphasis on turning performance, which
implies that the wing loading can be much higher. And it is very often the case
because of the amount of external stores carried. The comfort of the crew is
essential, because the aircraft is operating at high speed close to the ground,
in a hostile environnement (threats, meteorological conditions, navigation ,...)
The following aspects must be considered: flying clothing, harness, helmet,
anti"G" protection, ejection seat, cockpit conditioning, cockpit layout, noise
abatement, ride comfort, ... The primary requirement is to arrange the seating
position so that the pilot's neck and head are normal to the applied
acceleration, which means an almost upright position. But for other reasons, the
seat is slightly tilted. For instance, the value is 20 degrees on the TORNADO
aircraft.

If we consider now a multirole fighter, where emphasis is put on the
manoeuvrability of the aircraft, because it is easier to make a fighter bomber
aircraft from an air superiority aircraft than the opposite, the cockpit
arrangement and the inclination of the seat are so that the first requirements
will be adhered to. For instance, the seat of the F-16 is tilted at 30 degrees.
Having chosen a certain cockpit layout, taking into account all the requirements
mentioned here above, let us have a look to what is around the pilot, what kind
of instruments, displays, controls or switches are available. In one word, what
is the interface.

2   AIRCRAFT MAN-MACHINE INTERFACE

2.1 Roles of the Interface

The cockpit is where the pilot interacts with the complex systems used to
accomplish the mission of an aircraft. The role of a cockpit display is to
provide a visual communication link between a piece of aircraft equipment and
its human operator. For the link to be effective, it is necessary that the
information flows from the equipment to the display, but also from the
display to the human operator, allowing him to take action based on the
information. Each individual display requires the operator's attention which
has to be time shared with other displays and tasks.. And depending on the
segment of the mission (T/O, cruise, attack, LDG, ...)the attention of the
pilot will be more dedicated to some specific tasks than to others.

2.2 Historical Perspective

The necessity for information to be available to the aircrew of piloted
aircraft was realised from the beginning of manned flight, and although in
the early days considerable reliance was placed upon direct view of the
outside world, on board instrumentation was also used. This instrumentation
was installed primarily for measuring various parameters concerning the
condition of the aircraft, such as fuel gages, but also its position relative
to the outside world, such as altitude, speed and position. The older
displays were extensively used, with improvements and new devices and
possibilities. This increase in the number of instruments of various kind led
to the saturation of the man. The exponential growth of switches and
displays, resulting from the complexity of the mission, had to be located in
almost the same place available, with little concern for the pilot, who had
to be also located in the same room available. With the recent introduction
of Multi Function Displays (MFD), primarily Cathode-Ray Tubes (CRT), the
number of displays in the cockpit has been drastically reduced. Also the
number of switches, because one switch now has multiple positions, and
multiple functions also, creating "finger problems". This is why simulators
are used also to learn the switchology!

The increase of tactical data base, coming from various sensors, leads to the
need for some kind of automation.This modern concept of the computer
considered as a partner to assist the single pilot, is beyond the scope of
this lecture, but is undoubtedly the trend. The FIG.5 represents an old
cockpit, and the FIG.4 is giving an indication on what could be done for a
modern cockpit.

2.3 The Man in the Loop

Any weapon system is no more effective than its human operator. In that
sense, the system is merely an extension of the operator's sensory, muscular
and cognitive capabilities in responding to mission and environnemental
stress. To assure accomplishement of operational missions, the relationship
between man and machine must be complementary and compatible.

Very elaborate models of pilot are possible to study the situations of major
interest which are multiloop in nature. Mr. McRuer in Ref.5 describes the
crossover model which applies well to multivariable situations involving

several inputs. To simplify the problem, suffice to say that the attention of the pilot can be divided into two major tasks, namely control and management tasks. These two tasks are very often performed nearly simultaneously as parallel processing operations. In some complex situations, these two categories of tasks may require all the pilot's available attention.

The informations gathered (see FIG.6) are coming from several perceptual fields, such as: visual fields (foveal, parafoveal and peripheral), proprioceptive fields (vestibular), aural fields or tactile fields. Some other inputs can come from other fields, such as psychological ones for instance. Concerning more specifically the visual perceptual field, differences in threshold, dynamic properties or contrast backgrounds exists between the foveal, parafoveal and peripheral pathways. And coming to displays, it can be supposed that only foveal and parafoveal fields will be involved. It means that a task not requiring a high acuity property of foveal vision could be done with attention sharing between foveal and parafoveal pathway, while the foveal pathway is directed elsewhere (e.g. reading an instrument or conducting visual search). It means also that displays must have sufficient contrast with the environnement, which leads also to Military Specifications.

2.4 Physical and Environnemental Constraints

The importance of attention to human factors at the outset of design is recognized nowadays. A sound human factors implementation program, applied sufficiently early, can reap potentially great rewards by enhancing aircrew effectiveness and reducing development cost. Among the various aspects to be considered, such as flying clothes, helmets, anti"G" protection, ejector seat, cockpit conditioning, noise aspects and comfort in general, the cockpit layout and more specifically the displays used are of prime importance. CRT are intensively used, with monochrome or color tubes. The contrast must remain good in all circumstances, because the parafoveal vision, shared with the foveal field, needs a good contrast. Aircraft is manoeuvring rapidly from shaded to illuminated zones, in the clouds for instance, so that the light inside the cockpit is changing all the time. Other types of displays using Light Emiting Diodes (LED), Liquid Cristal Displays (LCD), Electroluminescent Displays (ELD), Vacuum Fluorescent Tubes, Gas Discharge or Plasma Displays can also be used and some of them have reached their commercial production. The interpretation by the pilot of numerous acronyms or signs used on different displays is a real problem. Engineers can put so many informations on a small place, that visual reception must be completed by an interpretation which can take extra time. This problem is partly solved by the use of simulators, but the choice of the acronym is of prime importance. Let us have a look to the environnemental effects, such as vibration and brightness in the cockpit. This last effect is very often encountered because the aircraft is manoeuvering in different illuminated zones. It is well accepted that the brighter the display and the greater the contrast with the background, the more easily it can be seen. But this is also valid during vibration, which can be quite significant in turbulence, specialy with low wing loading aircraft of to day. The movements of the head result in a decrease in visual performance, as a result of two mechanisms: the pursuit reflex and the vestibulo-ocular reflex, which are responsible for eye stabilisation. This is particularily true in the range 1-10 Hz. For further details see Ref.8.

3   INFORMATION NEEDS

The information which has to be presented to aircrew by visual displays can be broadly categorised into three types:

1 - Information concerning the functioning of the aircraft as a vehicule, including particularly the status and condition of aircraft, engine and armament systems.

2 - Information related to guidance, control and navigation of the aircraft vehicle, including position, velocity and attitude relative to earth axes and communications with the ground stations.

3 - Information dealing with the operation of payload systems, such as weapons and electronic warfare systems.

As avionics systems become more reliable and have greater computational and analytical capabilities, much of the information in categories 1 and 2 above becomes unnecessary, except in system failure conditions. The aircrew's information needs therefore shift towards category 3. This is illustrated by FIG 7, where a number of typical tasks are listed and the degree of automation which may be achieved is shown. The line between automation and aircrew task is more and more moving to the right with the use of sophisticated software and the introduction of artificial intelligence. The need to fly modern aircraft with

the head-up and the Hands On Throttle And Stick (HOTAS), implies that the most intensively used display is the Head Up Display (HUD), in which those abovementionned categories of informations are presented. Of course not at the same time, because too many symbols would be present on the display.

4   HEAD UP DISPLAYS IN GENERAL

This type of display will be discussed because it is the most used in modern aircraft, because also it is the theme for this Lecture Serie.
Optical systems used in conjunction with airborne displays can be classified according to their function as follows:

> 1 - rejection or minimisation of unwanted light which will confuse the view of the display. Sunlight rejection is the usual requirement and is frequently accomplished by the use of filters

> 2 - magnification and/or collimation. This is the classical use of conventional optics, in which the object plane lies on the display device and the image plane is positioned at some convenient distance from the observer

> 3 - combination of two or more separately generated images. This is generally achieved by the use of a plane combiner within a lens system and can be used for combining either similar or dissimilar optical images

> 4 - superposition of a display image over a direct view of the outside world

The HUD is probably unique in that most designs contain examples of all four functions. Nevertheless, different realizations make that a HUD is not only a modern gunsight used during WW 2, its capabilities are so broad because that system interacts directly with the human brain through the most adequate channel: the eye.

4.1   HUD with Conventional Optics

The classification listed above has the function of superimposing a display image over a direct view of the outside world, so that the pilot can receive information while he is looking straight-ahead and also when the pilot needs to align some displayed symbology with the real world. In both cases, it is necessary that the symbology be collimated. HUD of this type have proved to be highly satisfactory in service, but the Field Of View (FOV) limitations have been criticised and are now becoming a real obstacle to the use of HUD for night operations with Forward Looking Infrared Radar (FLIR) sensors and for the aiming and release of agile weapons. The optical module required makes also that a part of the aircraft's instrument panel is used when it could usefully be utilised by other important Head Down Display (HDD) The third main problem associated with this conventional HUD is the image brightness. For many years these limitations of conventional HUD have been recognized. The new technique, with diffractive optics to complement refractive one, can now overcome the limitations.

4.2 Diffractive optic for HUD

In conventional optics, rays of light are deflected according to the laws of reflection and refraction, which vary slightly with the wavelength of the light. But diffractive optics element deflects rays of light through angles which are highly sensitive to wavelength. The construction of diffractive optical elements having these properties depends upon the technique of holography. The hologram of a point source acts as a lens or a mirror and can thus be used for HUD collimation. Using optical elements of this type enables the construction of wide FOV on HUD. FIG.8 gives some comparison between conventional HUD and modern type. This last system, due to the numerous corrections to be made, either with conventional optics or with electrical inputs, is very complex and thus very expensive.

4.3 Gunsight type of HUD

The aim of this kind of HUD was to generate and present symbols which could be superimposed on external subjects, generally called a target. The collimation of this symbol is purely optical, and its pilotage assured by gyroscopic units. There are two reticles, one fixed and the other mobile, as showed in FIG.9. As a function of the armament selector, informations presented to the pilot include:
- information coming from the radar, usually distance to the target
- corrections to be applied in Air-to-Air (A/A), for the correct lead angle to be taken
- a position of the mobile reticle corresponding to a selected weapon in

Air-to-Ground (A/G), such as bombs, rockets or guns, and to parameters
such as altitude, speed, angle of dive, ...
- lateral and longitudinal informations, the artificial horizon for
instance, can also be presented

This kind of gunsight, for instance the one used on MIRAGE 5 aircraft, is
very old and the information coming from a mechanical collimation directed
by gyroscopic effects is lacking precision.

4.4 HUD of the F-16

The HUD unit displays information by projecting the image of a CRT through a
lens system onto a combiner glass. The display symbols on the CRT are derived
from horizontal and vertical deflection and can be brightened. This unit
provides visual flight information to the pilot. This information is derived
and processed externally to the HUD. There is a stand-by reticle, which acts
as a back-up in case the CRT fails. The block diagram of the unit is given in
FIG.10. The symbols are generated by the CRT and trasmitted through a filter
to the lens system before being sent to the combiner glass. The symbols are
collimated to infinity so that the pilot has no difficulty in viewing them
together with the external scene. The amount of information available is very
high, because in this case the F-16 is a multirole aircraft. The symbols are
computer-generated by units such as: the Fire Control Computer (FCC), the
Inertial Navigation Unit (INU), the Fire Control Radar (FCR), the Instrument
Landing System (ILS) or the Stores Management Computer (SMC), as indicated in
FIG.11. The information and the associated symbols are so numerous that the
use of a simulator is required to train the pilots. This type of HUD belongs
already to the "old" generation of equipement and wider FOV systems are now
coming into use. (see FIG.11)

5 PHYSIOLOGICAL PROBLEMS

In designing a man-machine interface there is considerable scope for changing
the machine side and minimal scope for changing the man side. The man's existing
sensors must be used and the information presented to these sensors in a way
which is as close as possible to the forms already familiar to him. Of the human
sensors available for use the eye has by far the greatest capacity as a receptor
of information flow from the machine to man. The other sensors (ear, fingers,..)
have maximum rates of information flow which are orders of magnitude lower than
those of the eyes, but nevertheless are useful for particular types of signals.
The effects considered here are only related to the eye and the external vision.
In man there are two neural control mechanisms which serve to stabilize the
image of a seen object upon the foveal retina. The first one, the
vestibulo-ocular reflex, is an open-loop system which makes use of information
from the vestibular apparatus to generate eye movements compensating the angular
motion of the head. The second one, the pursuit or fixation reflex, is a
closed-loop system which uses information from the retina to produce eye
movements that tracks the moving object in order to maintain the foveal image.
On either side of the head there are semicircular canals, disposed in orthogonal
axes, which sense movements of the head. Any trouble with these semicircular
canals will result in vision problems. This aspect will be studied hereafter
since they are affected by "G's".

5.1 Problems induced by "G's"

High "G's" operations are very common on modern aircraft. Of importance is
not only the peak G-level, but also the duration of "G" loads. On modern
aircraft, high values of "G's" can not only be reached (Instantaneous
Manoeuvrability), but can also be maintained during several seconds
(Sustained Manoeuvrability) over a large part of the flight envelope. A rapid
deterioration of mental and manipulative skills occurs before the black-out.
This kind of phenomenon is very often encounterd in dogfight, where rapid
changes of the velocity vector are needed. The outcome of dogfights is
therefore very dependent on the effects of the normal acceleration on the
visual acuity, use of limbs and mental activity. To consider only the visual
acuity, it is well known that loosing visual contact with the opponent means
very often the loss of the dogfight. Needless to say that the means of
improving the visual acuity are one of the focal points of activity in
designing high "G" cockpit. When "G's" are applied progressively the
black-out does not come all of a sudden. A grey-out phase will come first
where peripheral vision only is affected. It implies that the opponent must
remain in a forward cone or that the pilot has to move his head, which
creates other problems such as vertigo. Nevertheless this head movement is
very limited due to the reclined position of the pilot in the seat. If "G's"
are relaxed, the complete vision is recovered. But if they are maintained or
increased, a complete black-out can occur and can lead to "G" Induced Loss Of
Consciousness (GLOC), which is a real danger on modern aircraft because
leading generally to a fatal issue. It means that the pilot must modulate his

vision under "G" conditions. That needs some training and motivation, both being studied. Although the tilt of the seat is a good "G" threshold raiser, the anti-G suit is still with us, and it is a matter of fact that the use of this equipment means that a man can withstand 4 additional "G". Many studies are made on this type of equipment, but an important problem remains: the rapid "G" onset which can develop in modern aircraft, particularly for those assigned to A/A missions. Considerable research is done to overcome this problem, but the better matching of G-suit inflation and the high-G attainable rapidly by the aircraft is not yet assured.

5.2 Vertigo

Under this terminology all problems associated with horizontal and longitudinal references are considered. Vertigo can be induced by different external inputs such as: "G" effects, lack of structural stationary background, inputs from peripheral vision and inputs from the vestibular apparatus. These four cases, among other possible causes, will be considered.

5.2.1 "G" effects

The vestibular system is composed of three semicircular canals disposed in orthogonal axes, situated on either side of the head. This system senses all the head movements but also gives information of attitude to the brain. That means that it is very sensitive to apparent forces, such as those created by accelerations along any axis, or by any movement change in magnitude or in direction. That means that sensitive attitude cannot match with the real one. And to counteract the effects of apparent forces, the pilot must trust the instruments available, such as the artificial horizon, the turn-and-bank indicator, the attitude director indicator (ADI), etc... In these circumstances, a choice must be made on the priority given to instruments which do not match with sensitive impressions. To believe your feelings in flight can be fatal.

5.2.2 Lack of structural background

On modern aircraft, where external field of view is of prime importance, the absence of canopy or windscreen support structure and the fact that the pilot is seated far in front of the aircraft with no visual contact with the nose, make that there is no structural stationary background against which the display can be viewed. It follows that the information comes exclusively from the display, usually the HUD, without any means for the peripheral view of the pilot to make comparisons, in order to trust what the foveal vision information is giving.

5.2.3 Inputs from peripheral vision

As already mentionned, these inputs are very important because coming from the parafoveal or peripheral vision and they can induce misinterpretation of the information furnished by foveal vision. This is particularly true with the reclined position on the seat which makes an head-up attitude most comfortable. In this case, information is coming exclusively from the HUD whose FOV is rather limited. Information coming from elsewhere, from the peripheral vision for instance, can lead to a misinterpretation of the information and create some kind of desorientation or vertigo. This is particularly serious when flying through discontinuous clouds where a physical horizon cannot be found.

5.2.4 Inputs from vestibular system

This system is very sensitive to external forces, such as forces created by any acceleration.It means that some impressions induced by this system do not match with what the pilot sees or feels, resulting in some desorientation. In such a situation, the pilot must trust the instruments on board, and not his senses, particularly at night or in bad weather.

6   NEW SYSTEMS

Several new displays are envisaged for future cockpits, but we will consider only those related to vision. The problems which should be looked at are: wider Field Of View (FOV) and night operations. These two problems result in two different systems: Helmet Mounted Display (HMD) and Night Vision Goggles (NVG).

6.1 Helmet Mounted Display (HMD)

In order to gain some FOV capabilities, the idea to place the combiner glass on the visor of the helmet was studied. Moreover, this system is giving some

designation capabilities due to relative head movement. The necessity to align the aircraft with the object to designate, for aiming purposes for instance, is no longer mandatory. This system will be studied during the last part of this Lecture Series.

6.2 Night Vision Goggles (NVG)

Operations are mainly conducted during daylight. But a major effort is being made to operate also during the night. This results in NVG for the pilots, with all the attendant problems. This system will also be studied during the last part of this Lecture Series.

7 SIMULATORS

We address briefly the training of the aircrews on aircraft systems. This kind of raining is more and more necessary, due to the complication of the systems on board and also because modern aircraft are single seat. To avoid saturation of the pilot and to give him some confidence in the system operated, training is necessary.

7.1 Human Physiology

FIG 12 shows the physiological inputs to the pilot from motion and visual display systems. The vestibular system is in the inner ear and senses the orientation and rates of movement of the body. Some of the position sensing is done by tactile receptors, which trigger nerves when the skin is compressed or released, such as against the bottom or sides of the seat. The perceptual fidelity is the degree to which a pilot perceives the simulator to duplicate the aircraft. With regard to motion, this is highly dependant upon the washouts of the human system's motion sensing.

7.2 Need for Simulators

The simulators we are considering here are operated with the pilot-in-the-loop for system simulation only. It means that pilot can learn not only the switchology and the multiple symbols created by the computer, but also the tactical inputs, such as the threats for instance, which can develop during an actual mission. It is generally agreed that a systems simulation, to be effective, needs only visual cues, and motion is not necessary.

7.3 Visual Systems

The most popular visual system starts with either a model board or a computer stored data base. The image is then picked-up, processed and displayed to the pilot as either a real image projected on a screen or as a virtual image viewed through optics, as shown in FIG.13. Concerning Computer Generated Imagery (CGI), modern systems can display up to 10000 surfaces at one time. These systems also include horizon glow, visibility clouds, ground fog, lightning, horizon haze, target destruction, smoke and missile exhaust trail. One of the weaknesses of CGI systems, especially for precise handling, is time delay.

7.4 Motion Based Systems

A lack of one-to-one correlation between visual and motion cues can cause nausea and sickness. The need for correspondance is much greater in angular (rotation) cues than in linear (translation) cues. On the other hand, the tendency for motion sickness seems to be the strongest for the more experienced pilots, maybe because experience builds subconscious expectancy patterns. The conflict between what is expected and what is felt or seen causes confusion and vertigo.

8 CONCLUSIONS

As far as on board systems are concerned, HUD is probably the most widely used display. It has broad capabilities, when using computer generated symbols on a CRT, with inputs from multiple sensors. The HUD gives direct inputs to the human brain through the most adequate channel: the eyes. These are the most sollicitated by a lot of inputs, from the displays inside the cockpit but also from external sources, because the pilot has now an excellent external vision on modern aircraft. This results in saturation of the vision channel during all phases of the flight, but particularly when the workload is intense, in combat or at high speed low level. To alleviate this problem, training on simulator is necessary, which occurs mainly on fixed base simulators with a realistic model board and an excellent visual system.

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   AGARD-AR-228

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   D.E.A.HOUGHTON   AGARD-CP-257

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22 Advancement on Visualization Techniques   AGARD-AG-255

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   Air Combat Manoeuvring and the Use of Centrifuges in Performance
   Training   AGARD-CP-189

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29 Human Factors Aspects in High Speed Low Level Flight   J.L.DELL
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30 Combat Aircraft Manoeuvrability   AGARD-CP-319

31 Research on Visual Enhancement for High Speed Low Level flight
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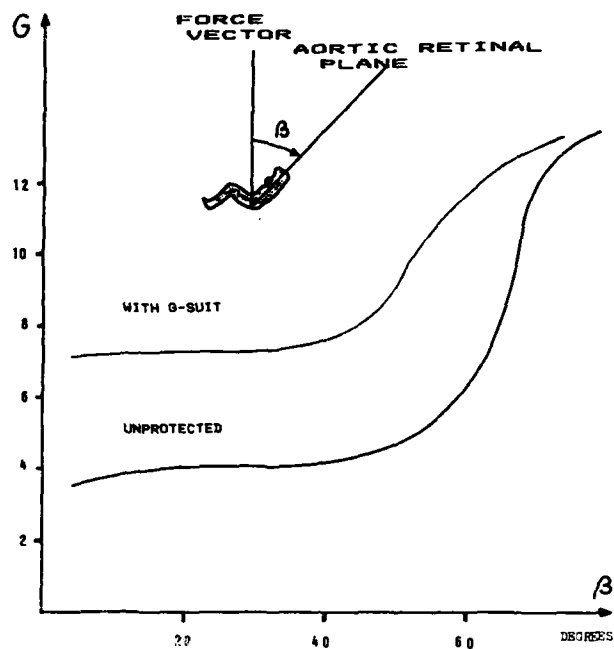32 Human Factors Considerations in High Performance Aircraft
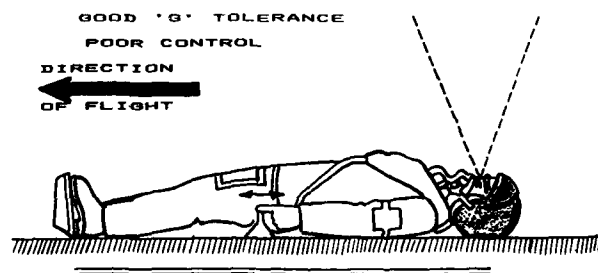   AGARD-CP-371

FIG 1 : INFLUENCE OF TILT ON ' G ' TOLERANCE
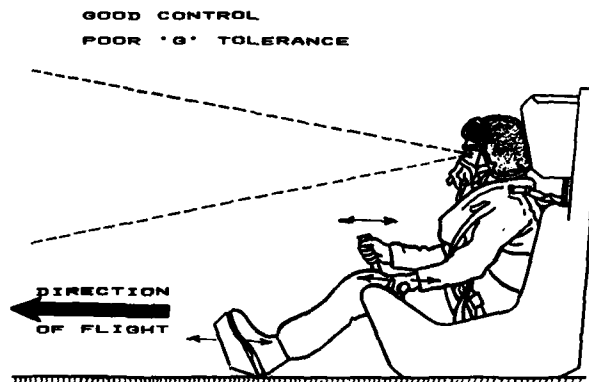

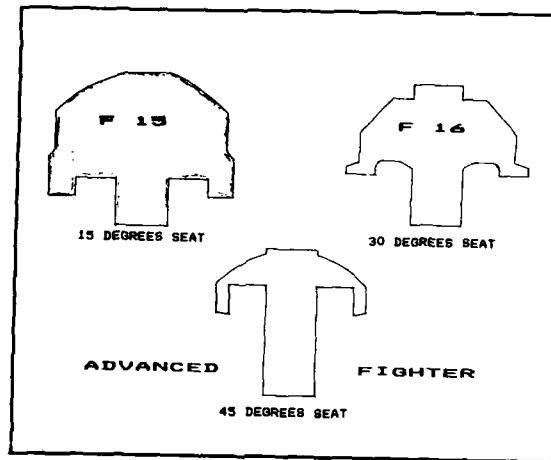FIG . 2 : SUPINE POSITION

FIG . 2 : CONVENTIONAL POSITION
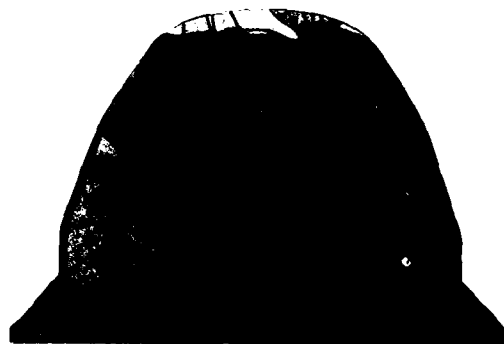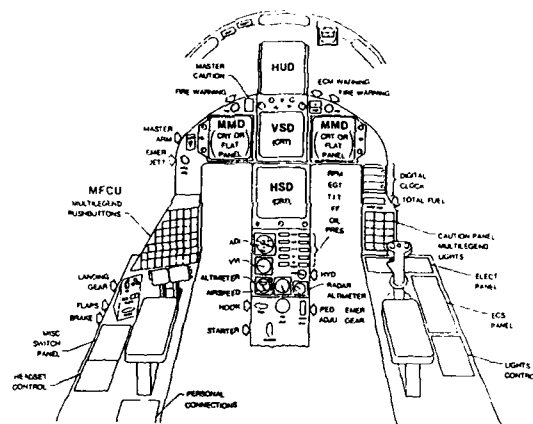
FIG 3 : FRONT PANEL AREAS

FIG 4 : FUTURE COCKPIT

Montre

Compas de secours — Accéléromètre — Répétiteur de fréquences

Enregistreur de visée
Indicateur radar altimètre
Indicateur de navigation
Crève-dinghy
Instruments de contrôle moteur-carburant
Poste de Cde Doppler
Verrouillage verrière
Frein de parking-secours
Commandes électriques
Tableau de pannes
Poste de Cde Tacan
Poste de Cde oxygène
Pressurisation-climatisation
Sécurités armement
Poste de Cde centrale gyro
Poste de Cde armement
Baladeuse
Poste de Cde PHI
Poste de Cde IFF
Boîtiers disjoncteurs
Interrupteur AUTO DROP

Viseur
Potentiomètre de gisement
Sélecteur gauche-droite
Indicateur de train
Instrument de contrôle de vol
Présentation et commandes ECM
Interdiction de tir
Largage charges
Commande parachute
Cde largage verrière
Aides au pilotage
Commande train
Indicateur niveau de vol
Radio
Manette des gaz
Eclairage cabine
Démarrage alimentation BP

Pochette à cartes
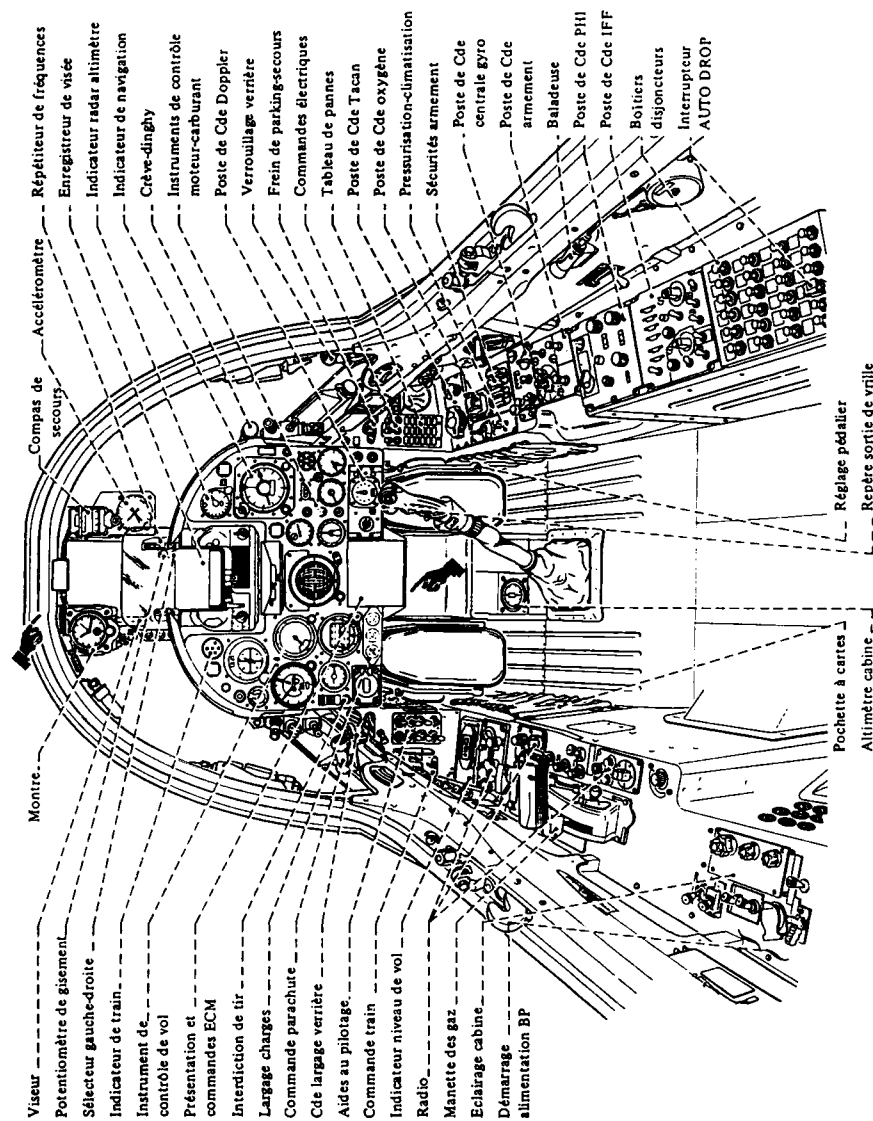Altimètre cabine

Réglage pédalier
Repère sortie de vrille

FIG 5 : TYPICAL OLD GENERATION COCKPIT

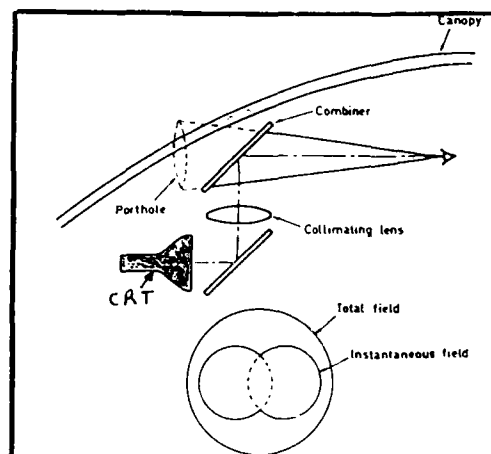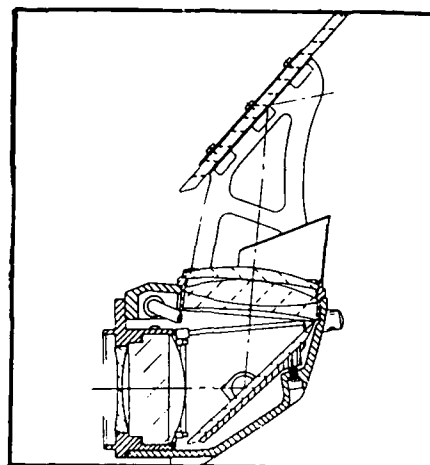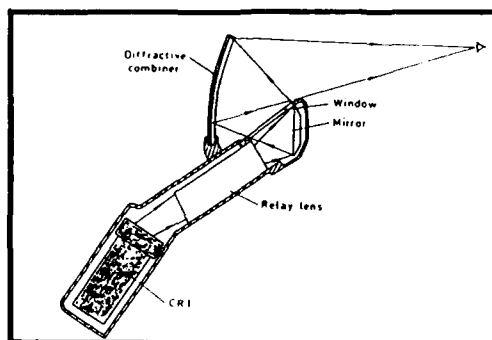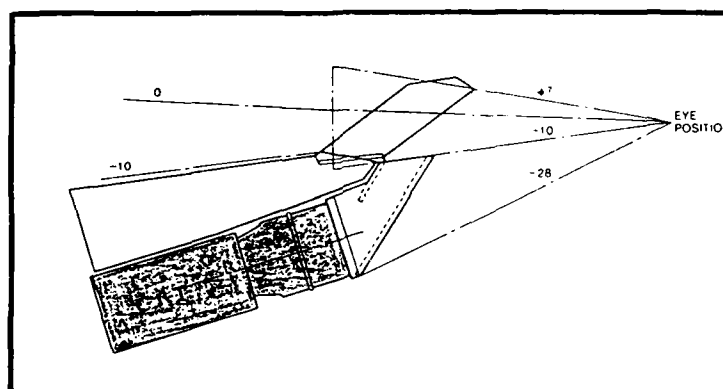FIG 6 :   SENSORY INPUTS

FIG 7 :   TASKS ALLOCATIONS

GENERAL ARRANGEMENT

OPTICAL MODULE
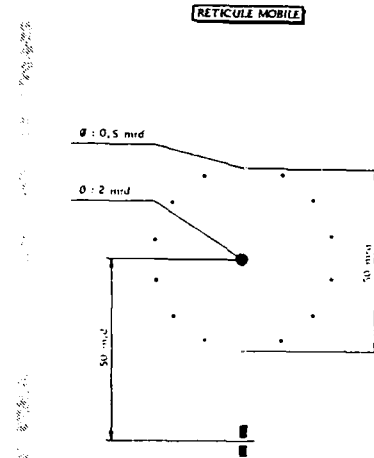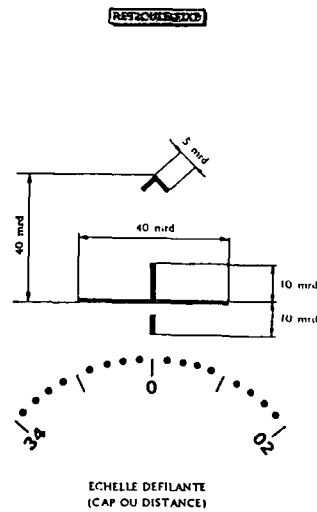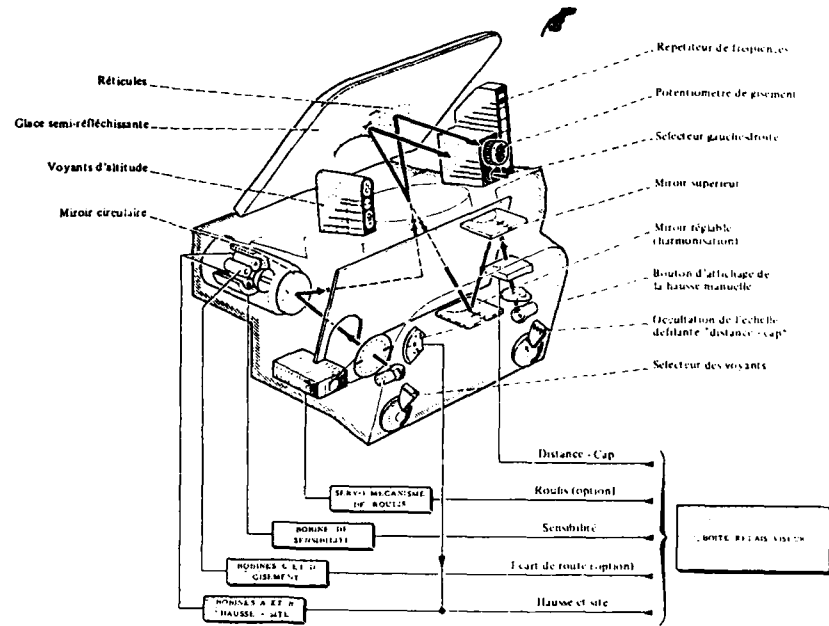
DIFFRACTIVE HUD SYSTEMS

FIG . 8 : HUD ARRANGEMENTS

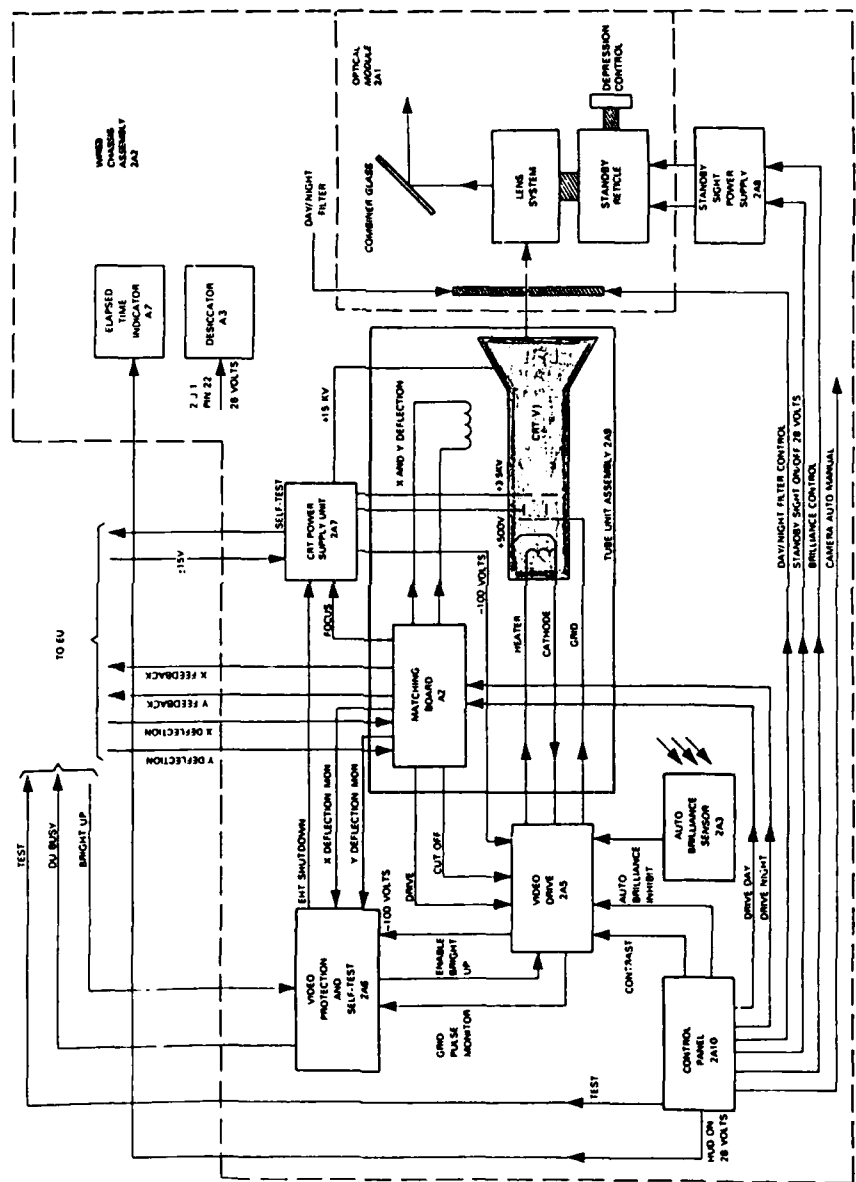FIG. 9 :   GUN   SIGHT   TYPE   SYSTEM

FIG . 10 : F 16 HEAD UP DISPLAY

FIRE CONTROL COMPUTER (left block) — inputs/outputs to **HEAD-UP DISPLAY**:

- FCC/HUD MODE
- AZ COR 1.4
- EL COR 1.5
- ILS CONST RL 1.4
- ILS CONST RG 1.6
- ILS CONST RL 5.6
- ILS CONST LML 1
- ILS CONST LMG 1
- ILS CONST RG 7,8,9
- SPARE WORD 4
- SPARE WORD 5

- DISPLAY WINDOW 7
- DISPLAY WINDOW 8
- DISPLAY WINDOW 10
- DISPLAY WINDOW 13
- DISPLAY WINDOW 14
- DISPLAY WINDOW 15
- DISPLAY WINDOW 19
- WINDOW 16,17,18 CNTL
- W16 CH1 & W17 FORMAT
- W16 CH2 & CH10
- W16 CH3 & W18 FORMAT
- W17 CHARACTERS
- W18 CHARACTERS

- SYMBOL CONTROL
- FPM (AZ,EL)
- DIAMOND (AZ,EL)
- ADJ RAD CIR (AZ,EL)
- 6 MIL RET (AZ,EL)
- STEERING CIR (AZ,EL)
- A/A TGT DESIG (AZ,EL)
- A/G TGT DESIG (AZ,EL)
- TISL TGT DESIG (AZ, EL)
- E-O RETICLE (AZ,EL)
- PUAC (AZ,EL)
- 8 MIL RET (AZ,EL)
- CMD STBS (AZ,EL)
- MOV WINDOW (AZ,EL)
- BFL END PT1 (AZ,EL)
- BFL END PT2 (AZ,EL)
- AIRCRAFT REF EL

- CONTROL WORDS 1-3
- E-M UPR STRUCT LIM
- E-M G AVAILABLE
- E-M G SUSTAINABLE
- E-M SPECIFIC ENERGY
- E-M ENERGY RATE
- E-M QUICKEST TURN
- E-M CURRENT ALTITUDE
- E-M SEA LEVEL X
- E-M FASTEST CLIMB
- E-M MAX PS AT LIMIT G
- RMAX, RMIN
- DIST AT 1 SEC TOF
- SIDESLIP
- HORIZ, VERT BAR
- SOLUTION CUE 1,2
- DESIRED ALTITUDE
- DESIRED SPEED
- ANG-OF-ATTACK ERROR
- CONTROL WORDS 4,5
- DESIRED COURSE
- RANGE GAP POSITION
- SEEKER CMD (AZ,EL)
- ADJUSTABLE CIRCLE RAD
- SCALE ELEVATION

- FCC OPERATIONAL

- HUD MODE
- MANUAL RANGE
- ROLL RATE
- PITCH RATE
- YAW RATE
- NORM ACCEL
- RADAR ALTITUDE
- HUD TEST STATUS 1
- HUD TEST STATUS 2
- HUD MODE WORD 2
- SEEKER POS AZ,EL
- INSTRUMENTATION

HEAD-UP DISPLAY — connections to right-side units:

FIRE CONTROL RADAR:
- FCR MODE
- SLANT RANGE
- RANGE RATE
- ANTENNA AZ,EL
- FCR MODE WORD 1
- SPARE WORD 2
- REL TGT VEL X Y Z
- FORE/AFT CURSOR DEF
- LEFT/RT CURSOR DEF
- TGT ACCEL X,Y,Z
- REL TGT RNG X, Y, Z
- ANTENNA TILT ANGLE
- FCR MODE WORD 2
- FCR TEST STATUS
- KALMAN CLOCK
- ANT AZ SCAN CENTER
- RDR-FCC ROLL CAL

INERTIAL NAVIGATION UNIT:
- INU MODE
- TIME TAG
- VEL X,Y,Z
- PLATFORM AZIMUTH
- ROLL
- PITCH
- TRUE HEADING
- MAGNETIC HEADING

CENTRAL AIR DATA COMPUTER:
- CADC MODE
- PRESSURE ALTITUDE
- BARO REF ALTITUDE
- TRUE AIRSPEED
- MACH NO.
- CALIB AIRSPEED
- TRUE ANGLE OF ATTACK
- PRESSURE RATIO (PS/PO)
- AIR DENS RATIO

INSTRUMENT LANDING SYSTEM:
- GLIDESLOPE DEVIATION
- LOCALIZER DEVIATION
- GLIDESLOPE DATA VALID
- LOCALIZER DATA VALID

INSTR MODE SEL/COUPLER:
- ILS SELECT

- MANUAL RANGE
- RANGE EXCITATION
- PWR EXCIT

CREW STATION WARNING LTS:
- WARNING
- WARNING RESET

FCNP:
- HUD READY

STORES MANAGEMENT SUBSYSTEM:
- SMS MODE
- DELIVERY MODE
- SEL WPN ID AND AMMO ID
- ROUNDS REMAINING
- RIGHT-LEFT REFERENCE
- AQUISITION LAMBDA
- SIGNAL RETURN
- PRECESSION (HEAD SLAVE)

- CAMERA PRE-RUN

VIDEO SYSTEM (NOTE):
- CAMERA RUN
- CAMERA AUTO
- CAMERA AUTO

LEGEND
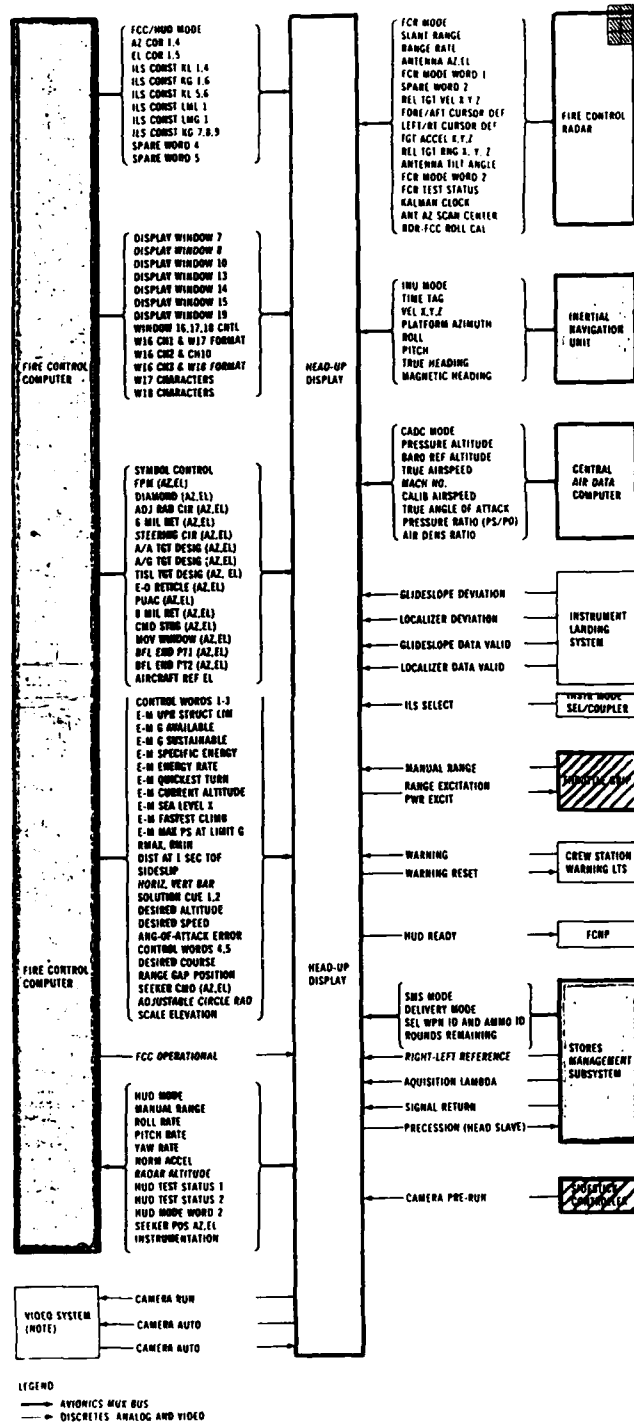→ AVIONICS MUX BUS
--→ DISCRETES ANALOG AND VIDEO

FIG . 11 : F 16 HUD INTERFACE BLOCK DIAGRAM
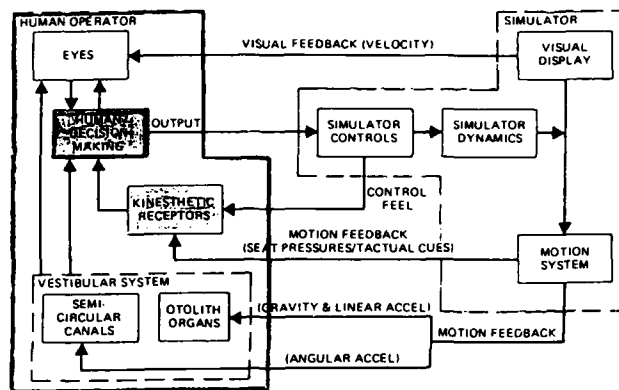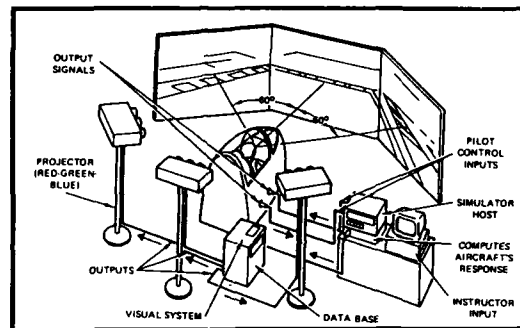
FIG . 12 : HUMAN OPERATOR INPUTS

FIG. 13 : REAL IMAGE SYSTEM

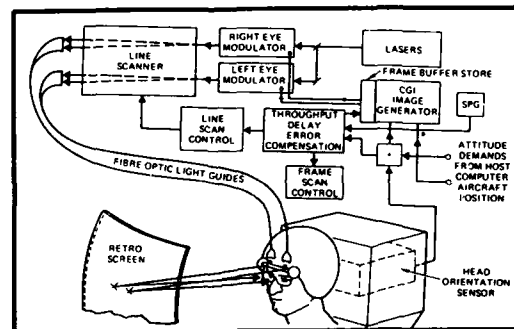FIG. 13 : VIRTUAL IMAGE SYSTEM

MAINTENANCE OF VISION-RELATED COMPONENTS

by

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3700 AM ZEIST
The Netherlands

SUMMARY

Visual obtained information is of the highest importance for the pilot
to fullfill his mission or in some cases to survive.
Though the pilot is offered more and more information by audio-means,
for example aircraft-warnings, the eyes of the pilot are his most im-
portant source of information.
Through maintenance of vision-related components it can be assured
that needed information can reach the pilot undamaged.
Within the Royal Netherlands Airforce this maintenance encloses mainly
cleaning, checking and replacement of the vision-related component.
As part of checking and replacement of the Head-Up-Display boresighting
is essential to assure a proper mounting, needed for accurate weapon-
delivery.

1. INTRODUCTION

In 1979 the Royal Netherlands Airforce began to replace the F-104G
Starfighter by the F-16 Fighting Falcon, an aircraft classified as a
High Performance Aircraft. At this time six squadrons are operational
with the F-16 in Air-Defence, Attack and Reconnaissance roles. Three
more squadrons, now flying NF-5, will be converted to F-16.
Modern technique provides information to the pilot in different ways.
Next to visual-obtained information the pilot has audio-provided infor-
mation at his disposal. For example Air-Traffic instructions, aircraft-
warnings, electronic-warfare warnings.
Ever since manned-flying visual obtained information through the eyes
of the pilot is the most important. Proper maintenance of the components
and systems concerned guarantees that the needed information can reach
the pilot undamaged.

Vision-Related components

The following components of the Fighting Falcon are considered vision-
related:

      a. Tranparency

      b. Head-Up-Display

      c. Other displays

      d. Lighting

Also painted surfaces in and around the cockpit can be considered vision-
related. For example glare-shield and panels.
See figure 1.
Next to this some parts of the pilot-equipment are vision-related, the
visor and the night-vision goggles. The RNLAF does not use night-vision
goggles for operational F-16 missions. Today they are in use by helicop-
ter pilots and under evaluation for the F-16 pilot.

2. MAINTENANCE

In general maintenance can be described by all activities performed to
keep or bring an item or system in the desired state.

HUD

GLARE-SHIELD

INSTRUMENT
PANEL

LEFT
AUXILIARY
CONSOLE

RIGHT
AUXILIARY
CONSOLE

RADAR/ELECTRO-OPTICAL
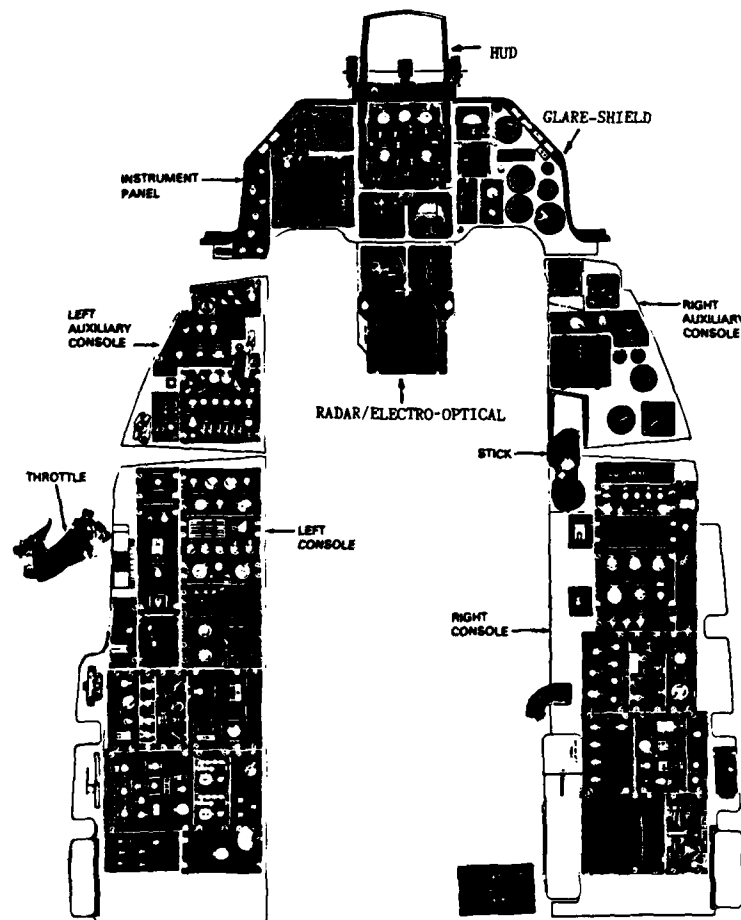
STICK

THROTTLE

LEFT
CONSOLE

RIGHT
CONSOLE

Figure 1 - Typical F-16 cockpitview

There are four different levels of maintenance. Each higher level makes
more profound maintenance possible, due to the availability of more
spares and facilities. This to avoid unnecessary investments of personal
and material.
The four levels are:

    a. first-line (by the user/using unit)

    b. second-line (by the base back-shops)

    c. third-line (by the depot)

    d. fourth-line (by industry)

According to the reasons of maintenance, it is distinguished in:

    a. preventive

    b. corrective

    c. modifications

Preventive maintenance takes place before a part or system brakes down.
It can be done on calender-basis, hours in use or after a special occur-
rence, for example excessive G-loads.
Corrective maintenance is performed when a part or system failed during
use or inspection. It includes repair and replacement.
Modifications are carried out to change the configuration of material,
although there is no failure. Often it increases serviceability,
performance or safety.

3. TRANSPARENCY

The transparency is a part of the canopy-assembly. This assembly provides
ready access to the cockpit, environmental protection for the pilot,
maximum visibility during operation, and rapid egress of the pilot in
case of an emergency.
Different from most other jet-fighters, the F-16 has no seperate wind-
screen. This is included in the canopy-assembly, which shows a typical
drip-shape of the transparency, giving the pilot an excellent outside
view (figure 2.). The transparency covers the front part of the cockpit.

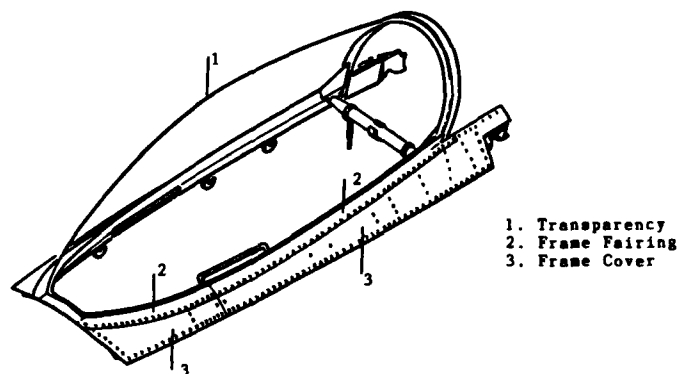1. Transparency
2. Frame Fairing
3. Frame Cover

Figure 2 - F-16 Canopy Assembly

Depending the manufacturer the transparency is constructed of a single
ply, optical grade polycarbonate plastic, or is a laminated construction
of polycarbonate and acrylic plies. Often the transparency is coated
with a protective film, wich can be found on the in- or outside surface,
even some times on both surfaces.

Cleaning and polishing

First-line maintenance of the transparency is performed daily by the
crew-chief. When necessary the transparency is rinsed or cleaned during in-
spections with a mixture of water and isopropyl alcohol, or water and
liquid soap, using cheesecloth or a disposable towel. This will remove
loosely adhered dirt and dust particles. To avoid damage to the plastic
there is maximum of alcohol by volume in the mixture.
When the protective coating becomes eroded and some areas show streaks,
that will appear hazy, especially during a flight through clouds contai-
ning ice, the pilot will order canopy-polishing with plastic-polish,
accomplished by the crew-chief.
Cleaning should be accomplished only when the accumulation of surface
contaminants will obviously degrade the imaging quality the transparency.
This means that a scheduled periodic cleaning, regardless of condition
is to be avoided.

Rain-repellent

Once a month, after aircraft-cleaning, and also when necessary, to be
determined by the pilot, the crew-chief will apply rain-repellent, which
creates a very thin and very smooth film on the transparency, preventing
water to attach.

Replacement and repair

Due to flying optical blemishes, scratches and coating-loss (peeling) can
occur in such a large number of combinations or possibilities that pilots-
performance can be decreased, especially when this happens in the prime-view
area of the pilot, wich is the central area in front of him.
If cleaning and polishing fail to solve the problem of scratches the trans-
parency has to be replaced. Pilot's opinion always turns the scale.
An other criterion for replacement are cracks found during inspections.
Only seldom cracks occur in the visible part of the transparency. It can
happen as result of a bird-strike.
Most cracks are discovered in the edge, and growing out of the bolt-holes.
Causes for these cracks are believed to be residual stress, induced during
fabrication, thermal stress, as a result of extreme temperature-changes, and
cabin-pressure. At some manufacturers the designer, aware of crack-possibi-
lities, introduced a crack-stop groove, preventing an excisting crack to grow
outside the canopy-frame area.
For all possible cracks the Technical Orders give rejection criteria. In some
cases can be treated by stop-drilling. With this technique the back-shop speci-
alist drills stop-holes to intercept the crack. To accomplish the drilling it
is necessary to remove the transparency from its frame. This has to be done
also in case of disapproval of the transparency. It means removal of the canopy-
assembly from the aircraft and transportation to the back-shop. There the trans-
perency will be loosened and taken out of the frame. The repaired or new one
is then placed in the frame, with a sealing-compound between transparency and
frame. Finally 78 bolts are placed and fastened.
All transparencies have a slightly different shape, and although they are
placed in the frame under stress, the canopy-assembly will have a different
shape. This makes rigging of the assembly during installation necessary in order
to get the frame flush with aircraft-surfaces.
Although within the Royal Netherlands Airforce transparencies with severe scrat-
ches or heavy peeling are not yet repaired, it is pcssible for the manufacturer
to remove a lot of scratches. depending location and depth, and to restore the
protective film. After removal of scratches in the front section of the trans-
parency the Correction Coefficient can be changed. This coeffient indicates a
correction for the optical turn-off by the transparency. The figure, assessed
by the manufacturer, must be put in the Fire Control Computer and adjusts the
location of weapon-delivery information on the HUD.

4. HEAD-UP-DISPLAY

As part of the Pilot Display Unit the HUD provides visual flight-information to
the pilot. This information is derived and processed externally to the HUD, for
example by the Fire Control Computer and Inertial Navigation Set, and is display-
ed from a Combiner Glass into the infinite.
The HUD is positioned in front of the pilot and enables him to look through the
combiner glass and the transparency, seeing flight-information and the outside
at the same time in the same view. See also figure 3.

Figure 3 - Pilot Display Unit

Cleaning

During the pre-flight inspection the crew-chief cleans the combiner
glass and PDU-lens. Dust is to be removed with a hair-brush or air-
syringe. Next the glass and lens will be cleaned using lens-paper and
lens-cleaner.
After replacement or repair in the Avionics Intermidiate Shop (AIS)
the back-shop specialist performes the same job and cleans also wiring
and connectors.

Repair

Deficiencies in this system can be electronical and mechanical. In case
of an electronic malfunction of the HUD the cause can be an other system
that derives and processes the information. This system has to be repla-
ced and repaired. But also a PDU-failure is possible. Then the PDU is
removed and transported to the AIS or even industry for repair.
Although little change, due to the intensive use of protective covers,
the HUD can suffer scratches and chips on the combiner glass. Since the
introduction of the F-16 this has never been reported in the Dutch Air-
force. For noticed scratches and chips the T.O. gives rejection criteria.
See figure 4.

ZONES A & D SCRATCHES AND CHIPS
PERMITTED
ZONE   B   SCRATCHES PERMITTED
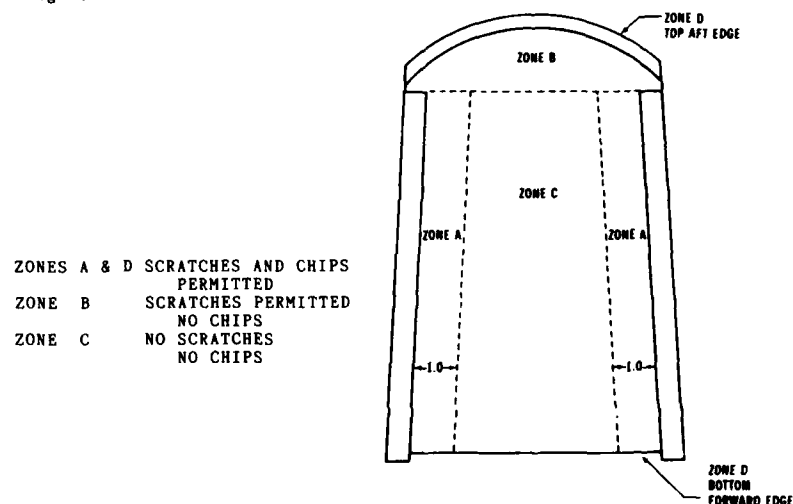NO CHIPS
ZONE   C   NO SCRATCHES
NO CHIPS

Figure 4 - HUD Combiner Glass Rejection Criteria

When rejected, also in case of cracks, the combiner glass has to be
changed for repair is not possible. Change of the glass by the AIS
includes a boresight. Then instead of the PDU-lens a lamp will be
installed and the position of the glass is checked with an optical
instrument.

5. OTHER DISPLAYS

Next to the HUD there are other displays in the F-16 cockpit, often
called Head-Down-Displays. Figure 1 shows the Radar/Electro-Optical,
various instruments, Stores Management Display (digital) and consoles
with switches and readings.

First-line maintenance

Maintenance performed by the crew-chief is limited to cleaning. Dust
and other foreign matter is removed using hair-brush or cheese-cloth.
When surfaces are smeary they have to be cleaned with lens-cleaner or
a mixture of water and isopropyl alcohol.

Higher maintenance

In case of malfunction or damage the unit involved has to be removed
by the back-shop specialist, who installs a new one, wich will be
checked for proper functioning. The disapproved item is repaired, if
possible, according T.O.'s at base-, depot- or industry-level.
However, due to location and position of these displays only rarely
scratches are found. Most replacements are to solve malfunction.

6. LIGHTING

Lighting can be devided into two parts, exterior and interior. For the
F-16 the exterior-lighting includes taxi- and landinglamps, navigation-
lights and a flood-light to enlight the aerial-refueling receptacle if
necessary. Only taxi- and landinglamps are direct vision-related.
The interior-lighting includes instrument- and cockpitlighting. Each
instrument does have its own lights. If a lamp fails to light the first
action is to replace the bulb, either by crew-chief or by back-shop-
specialist. Some times the instrument has to be removed and brought to
theshop for repair. It is not always a lamp-failure, also power-failures
are possible. They have to be solved by the back-shop specialist.
The cockpitlighting consists of panel-lights and two utility-lights,
which can be used by the pilot to enlight his maps and flight-informa-
tion booklets. For both systems the same procedures apply: cleaning,
repair and/or rer. cement. Cleaning is done by the crew-chief using
cheese-cloth and little isopropyl alcohol. Replacement of bulb is
first-line maintenance as well. Power-failures and total replacement
are usually solved by the back-shop specialist. Most of the light-assies
cannot be repaired and have to be replaced by new.

7. PAINTED SURFACES

All bare metal in and around the F-16 cockpit is painted, first with
primer and then with dull black or grey paint. This is done for two
reasons. First to protect the metal against corrosion. Second to avoid
reflections of sun and lights, which may disturb the pilot.
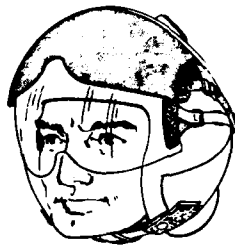
Maintenance

The painted surfaces should be kept free of dust and other foreign matter.
Cleaning can be done with a hair-brush or cheese-cloth.
Where scratch mark or dents penetrate to bare metal painted surfaces have
to be spot-painted with primer and paint.

8. VISORS

The pilot's helmet is equipped with at least one visor, that provides
protection to the uncovered parts of the pilot's face, especially his
eyes. In case of an accident or bird-strike losse parts can enter the
cockpit and hit the pilot.
The Dutch F-16 pilot wears a helmet with a light-weight strap, dual visor
system. The light-weight aspect is very important in relation to the
G-loads. One visor is normally clear, the other neutral gray to minimize
the effect of sunshine. See figure 5.

CLEAR VISOR "LOWERED"
GREY VISOR "RAISED"

Figure 5 - Light-weight Strap, Dual Visor System

Cleaning and replacement

The only maintenance performed to the visors is cleaning and, if neces-
sary, replacement. Before and after every flight the visors are cleaned
with a soft, lint free, cloth, using isopropyl alcohol and/or clean
water. Damaged visors, no longer accepted by the pilot are replaced by
new ones. Repair is not possible or not cost-effective.

9. NIGHT VISION GOGGLES

Since a few years night vision goggles are in use by Dutch helicopter
pilots. Just recently a flight-test was performed in the F-16.
Night vision goggles are attached to the flight-helmet. Simultaneously
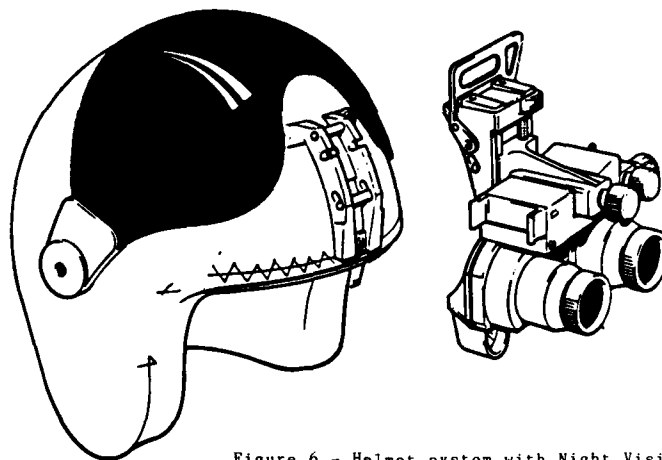use of visor and goggles is not possible. See figure 6.

Figure 6 - Helmet system with Night Vision Goggles

Maintenance

Maintenance to the night vision goggles is very limited. It includes
cleaning of the goggles, especially the lenses, using lens-cleaner and
lens-paper. Although scratches and other damaged are hardly found, the
only solution is to replace the involved part.
Special attention is demanded by the power-supply of the system. Two
1.5 Volt batteries power the Image Intensifier. Every two flight these
batteries are changed to assure power is always sufficient for proper
functioning.
All maintenance is performed by the Life-support equipment specialist
in the flying squadron.

10. BORESIGHT

It is essential that the weapons-system provide the most accurate
weapon-delivery to the target that is possible. To insure this overall
accuracy, boresighting of the weapons-system is performed. In basic
this means that components of the weapons-system are aligned to a
reference line. The components of the F-16 requiring boresight are the
Head-Up-Display, Fire Control Radar, Inertial Navigation Set and Gun.

Boresight Theory and Principles

With earlier aircraft, like the F-104G, boresighting was necessary after
each removal and installation of weapons-system components. Each compo-
nent was aligned to a reference line. This was very intensive labour,
and happened often after a component-failure and -replacement. This
decreased aircraft-serviceability.
With the F-16 the mounts and mounting-pins of the components are bore-
sighted. This means that boresighting is no longer required after every
replacement of weapons-system components. It decreases the mean time for
repair enormously and thus increases aircraft-serviceability.

Boresight Requirements

The requirements for performing boresight procedures on the F-16 are based
on four main conditions:

    a. Hard landing, criteria are contained in the Flight Manual

    b. Excessive G-loads, in accordance with T.O.

    c. Replacement of mouts or mounting-pins

    d. Pilot-reported discrepancy

Boresight Technique

The weapons-system utilizes the aircraft boresight reference line (ABRL)
and aircraft pitch and roll angles to determine the alignment required
when boresighting. Various special tools and instruments are used to
establish the ABRL. See figure 7. In basic two fixtures are installed on
the aircraft. One in the Main Landinggear Wheelbay and the other in the
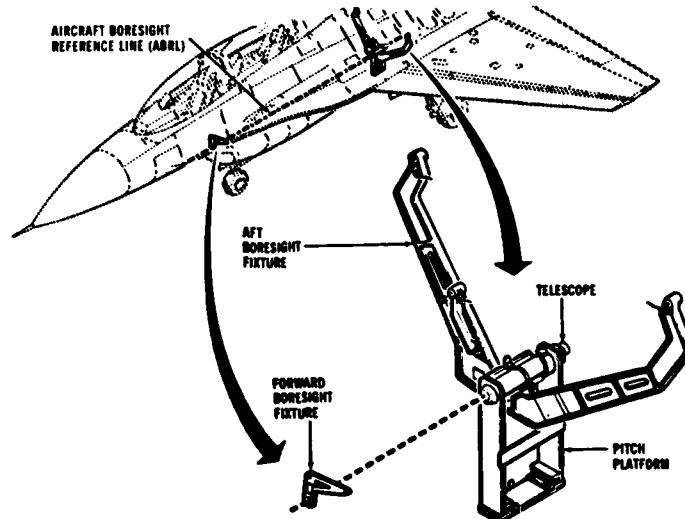Nose Landinggear Wheelbay.

Figure 7 - Aircraft Boresight Reference Line

After installation of the two fixtures the ABRL is established by
looking through the telescope into the forward fixture reference
target. Using a clinometer (see figure 9) the aircraft pitch and
roll angles are determined.

To boresight the component-mount and -mounting-pins various fixtures
are in use. These fixtures are placed on the mounts or mounting-pins
and also fixed to the aircraft-frame. This results in the fixation
of mounts and mounting-pins in the required position, using the ABRL
and determined aircraft pitch and roll angles. After fixation of the
mount(ingpin) is locked.

There are two techniques to lock. When boresighting the mounting-pins,
the space between the pin and its housing is filled with kit. While
still fixed by the fixtures the kit has to cure, approximately 72 hours.
When everything goes well the fixture will be removed, the mounting-pin
has been boresighted and the component can be installed.

While boresignting the HUD, the HUD-mount is put in the required posi-
tion by turning the turnbuckles, using the HUD boresight alignment tool
and HUD and GUN boresight fixture. See figures 8 and 9.

When the mount is positioned as required, the locknuts and mount-bolts
will be torqued. Finally the special tools are removed and the PDU can
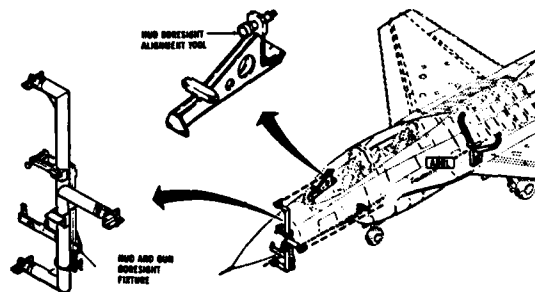be installed, completing the HUD boresight.
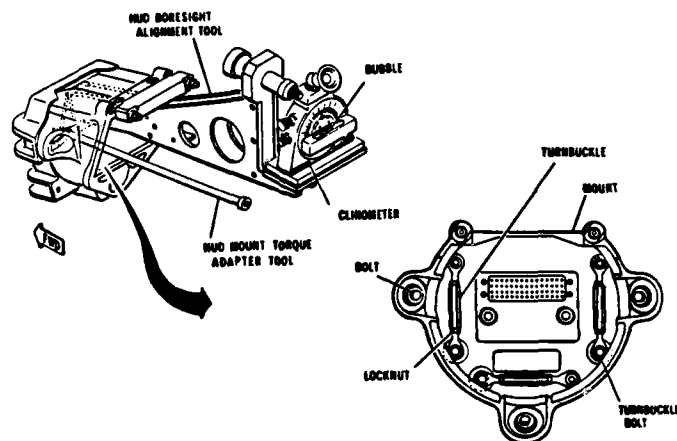

Figure 8 - HUD Boresight Tools

Figure 9 - HUD Boresight

Quick and Confidence checks

If angular deviations between installed equipment and aircraft reference
line and angles are suspected, for example when weapon-deliveries are
continuously   of range, a boresight confidence check will be performed.
With this confidence checks the various fixtures are placed on the still
fixed mounts and mounting-pins, after removal of the weapons-system
components. The check is performed and when angle-differences are within
limits as described in the T.O., reboresighting is not necessary. Bef
Before performing a confidence check on the PDU/HUD-mounts a quick check
has to be accomplished, using a template assembly. The template is placed
on the PDU-lens, and the Standby Reticle is switched on. This gives an
image of template and reticle from the combiner glass. At the same time
the pitot-tube of the aircraft is visible through the HUD. The position
of this tube on the template-image-line must be within limits. Also the
position of the reticle-diamond must be within limits with regard to both
pitot-tube and template-image-line. If at least one position is out of
limits, the confidence check must be performed.
The quick check can be accomplished in a few minutes, giving a fair judge-
ment on the necessity of the confidence check, which will take at least
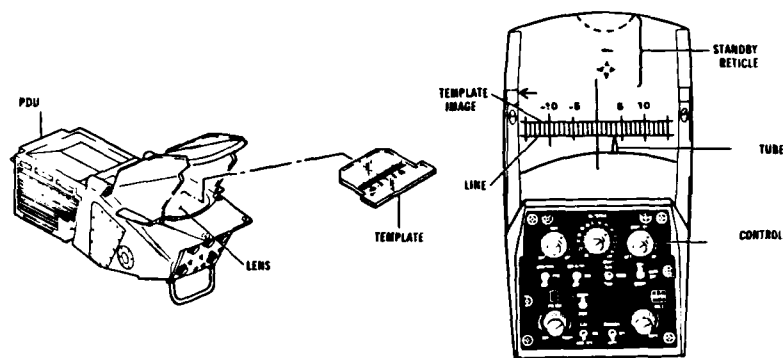8 hours. See figure 10.

Figure 10 - Quick PDU/HUD Boresight

Boresight conditions

Before performing a boresight or confidence check certain input-conditions
must be met.
The T.O. mentions access doors and panels that have to be installed and
secured properly. All equipment forward of the airintake must be installed
or replaced with ballast of equal weight. This to insure proper weight and
balance and overall structural integrity. However, fuel quantity and engine-
installation are optional. The aircraft should be parked out of direct
sunlight as metal will expand and contract due to heat gain and loss.
Vehicle movement in the boresight-area must be prevented and when boresigh-
ting in the open windspeed should be less than 10 knots to prevent any
unexpected aircraft movement.
Only recently it was discovered that an aircraft, needing a boresight and
being on jacks for some time with doors and panels removed, has to fly
several times to regain a final and constant shape, before performing a
boresight. Otherwise the boresight will never be successfull.

11. CONCLUSIONS

Although the vision-related components in High Performance Aircraft like
the F-16 are designed to provide the pilot as much as possible visuable
information without interfering in his flight-performance, the designer
must have had an eye for maintenance. Most components are easy to main-
tain at the lowest maintenance level, and in case of rejection easy to
replace in minimum time, which benifits aircraft-serviceability.
Rejection criteria are written down in Technical Orders, but the pilot
always has the last word in rejection-discussions.
The transparency and HUD require more attention and maintenance than
the other vision-related components, because they are very important

for the quality of the image presented to the pilot.
The transparency is vulnerable, due to the large plastic surface and
exposure to environmental threats. This requires daily-cleaning, and
polishing and rain-repellent application. Scratches are hardly remove-
able at base-level and make replacement obliged.
The HUD mostly suffers *electronic failures and is then repaired in the*
AIS or by industry.Mechanic failures hardly occur. Only cleaning of
combiner glass and PDU-lens is required.
PDU/HUD-change does not include boresight. Boresight is seldom perfor-
med and only based on four main conditions. The technique used on
F-16 minimizes the need for boresight, just like the possibility of
confidence and quick checks. This increases aircraft-serviceability.

NIGHT LIGHTING AND NIGHT VISION GOGGLE COMPATIBILITY

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SUMMARY

Proper lighting of aircraft instruments, panels, controls, indicators, and displays is essential in high performance aircraft. The lighting must be useable over a large range of ambient conditions; especially during dawn or dusk transitions and at night. It must be uniform, have low glare, and be continuously dimmable to very low luminance levels, so the pilot can become partially dark adapted for good, out-of-the-cockpit vision. Various aspects of cockpit lighting such as intensity levels, contrast, luminance and color uniformity, red versus white versus blue-green general lighting, color coding, and other parameters are discussed. Daytime lighting requirements will be noted throughout the paper because they are an important part of the overall design of the lighting system.

A special area of interest is night vision goggle compatible cockpit lighting. As night missions evolve, night vision goggles (NVGs) are being used with greater frequency. The characteristics and usage of NVGs are over-viewed. Methods of achieving night vision goggle compatibility in the cockpit using filtered incandescent lamps, external bezels, floodlighting, light-emitting diodes, electroluminescent lamps, microlouver material, and black flight suits are described.

COCKPIT LIGHTING

Instruments, panels, switches, controls, indicators, and displays must be visible over a very large range of ambient lighting conditions. Ambient illumination ranges from 10^5 lux (10^4 foot candles) unobscured sunlight at altitude to a moonless, overcast night sky which is approximately 10^{-4} lux (10^{-5} foot candles). In the daytime, instruments and panels utilize the natural ambient light to be visible, whereas multifunction displays and annunciator signals must have high luminous output and good contrast to compete with the sun. Another demanding ambient condition occurs during dawn and dusk transitions. The cockpit can be in very dark shadows while the pilot is still viewing a very bright outside scene. The human eye can adapt to scenes that have about a 100 to 1 luminance range, while a dawn/dusk situation easily exceeds 1000 to 1. Depending on the sun angle, the pilot will turn the cockpit lighting to maximum, which is only 1 to 2 foot Lamberts (ft-L) for instruments and panels. Fortunately, this condition is of short duration. As the ambient illumination lowers, the pilot dims the cockpit lighting levels to reduce internal windscreen glare and increase his out-of-the-cockpit vision.

Dimming circuits are required to compensate for variations in the ambient illumi-nation, different missions, individual pilot differences and preferences. Old style dimming circuits used discrete position switches that usually resulted in poor control-lability. Continuously variable dimming is now used in most modern aircraft. Since the eye perceives logarithmic changes in luminance as near linear-like changes in subjective brightness, the dimming circuits should vary luminance logarithmically. To be effective throughout the entire ambient range, good controllability must be main-tained from the 1 ft-L maximum through about 0.001 ft-L minimum before extinguishing (MIL-L-87240). Associated with dimming is tracking. As instrument and panel lighting is varied by the master control, individual units should appear close in brightness to each other. This is especially critical in the very low luminance range. For example, if an important instrument is dimmer than the others, a pilot will often turn up the master dimmer control until it is readable, but the rest of the instrument suite would then be brighter. Not only will this increase glare and internal reflections, but the entire cockpit also acts as an adaptive field to the eyes. The higher the adaptive field, the less sensitive the eyes will be to faint (near threshold) out-of-the-cockpit lights. It is for these reasons that the lower a cockpit can be uniformly dimmed, the better the external vision. To this end, some aircraft have individual dimmers, acces-sible by maintenance personnel, to balance out the lighting. When a new instrument or panel is installed, rebalancing may be required. Unfortunately, this balancing procedure is time consuming and has to be done at night by at least two people. Also, balancing requirements can reflect individual pilot visual differences or preferences in lighting, and aircraft are flown by different pilots on any given mission. Ideally, the individual trimmers would be accessible to the pilot, but the additional controls contribute to the complexity of the cockpit.

In an effort to verify cockpit lighting requirements, a field study was conducted by this laboratory at Eglin AFB, Florida. The study measured several qualities that related to night vision and lighting. Seven pilots served as subjects. Each pilot was dark adapted for at least 30 minutes. He then put on red goggles and was taken to either an F-15 or F-16 aircraft that was located at a dark, remote section of the

field, away from lights. The pilot was seated in the aircraft, then instructed to remove his goggles and adjust the cockpit lighting to his normal nighttime settings. The windscreen was in the lowered position. The pilot then replaced his goggles and moved to a waiting area. Photometric equipment was then installed and luminance measurements of the pointers were taken on the airspeed, angle-of-attack, attitude direction indicator, horizontal situation indicator (HSI), altimeter, vertical velocity indicator, revolutions per minute (RPM), and temperature gauges. Mean instrument luminance readings (both aircraft) ranged from 0.04 to 0.023 ft-L. The lowest reading was 0.003 ft-L and the highest was 0.089 ft-L.

The tests were followed up by a questionnaire on cockpit lighting. All of the pilots felt the dimmers for these two aircraft had good controllability in the low end and the instruments could be dimmed as low as needed. Most pilots adjusted the main instruments to slightly higher levels than the side consoles. They preferred to read important main instruments, but with other instruments (such as RPM), they looked at pointer position only and these were often set at lower levels. Variations in luminance among instruments (balance) caused higher than desired setting. For example, the HSI had a poorly illuminated tumbler readout. Due to its importance, the pilots turned up the master dimmer so they could read the numbers, which in turn caused higher luminances and increased windscreen reflections. Maximum obtainable luminance settings were judged adequate. They were used for pre- and post-flight checks and dawn/dusk transitions. The side console panels created the most glare and reflections. Pilots often used small floodlighting to even out the cockpit illumination. As indicated by the data, dark adapted pilots set their instruments very low, thus verifying the minimum luminance, uniformity, and controllability requirements set forth in MIL-L-87240.

Contrast is as important a requirement as luminance and dimming. Except for color coding, instrument and panel surfaces are matte black with white markings, which yields the highest contrast over a large range of viewing conditions. Contrast is usually defined in military specifications as the difference between the scale and background luminances, divided by the background luminance. A contrast of 12 is typical for white markings and pointers on black backgrounds. A contrast of five is recommended for white on gray. Higher contrasts can be obtained by varying paints or using filters. However, very high contrast at night is not recommended since it can induce a visual illusion termed the autokinetic effect. Bright light sources (especially point sources) that have very dark surrounds may appear to be floating or moving when in fact they are stationary. Early lighting systems had luminescent paint markings on a black background and were floodlighted with ultraviolet light. Besides causing eye strain and increasing the risk of cataracts, the instruments had extremely high contrast, which had the undesirable result of inducing the autokinetic effect.

Over the past 20 years, cockpit lighting colors have changed from red, to white, and now most recently, blue-green for night vision goggle compatibility. Red was used to help maintain the pilot's partial dark adaptation because, at that time, out-of-the-cockpit vision was very important. There were several disadvantages which included eye strain and focusing problems that caused fatigue over time. Color coding of maps and instruments was also limited. As the pilots' eyes began to be supplemented by radar and other sensors, white lighting began to be employed. The main advantages of using white-lighted instrumentation were lower eye fatigue, higher visual resolution, and more effective use of color coding. For modern fighter aircraft, the US Air Force uses white lighting. Night vision goggle compatible lighting is blue-green because the red and infrared components have been eliminated due to their interference with the goggles.

When the pilot is looking out of the cockpit at night, the instrument and panel luminances act as an adapting field. Different average adapting luminances cause corresponding threshold changes, or levels of partial dark adaptation, for detecting a faint stimulus like a distant aircraft light. The color of any given field luminance also affects the eye's level of dark adaptation. Smith and Goddard (1967) measured the effect of cockpit lighting color on dark adaptation. The 50 percent probability of detection thresholds and 90 percent confidence limits were calculated. For a given adaptive luminance field, the probabilities of detecting the presence of a 200 micro ft-L stimulus were approximately 0.935 for red, 0.54 for white, and 0.3 for green lighting. The difference between thresholds after exposure to a green adaptive field versus the red field was statistically significant. Green versus white and white versus red comparisons showed no statistically significant differences between detection thresholds. It should be noted that the experimental setup used a flood-lighted instrumentation panel which resulted in a large illuminance of the retina that would not be found in an edge-lighted suite. Also, the difference between the pure red and green conditions are a worst-case condition not usually found in a regular, color-coded (mixed colors) cockpit. Both of these factors caused larger threshold differences than would be expected in a real cockpit. From an operational standpoint, it is unlikely that different colors cause a significant decrement in the pilot's ability to detect faint lights outside of the cockpit, especially when considering the variability among crew members' vision and the large amounts of light emitted from populated areas. Also, the broadband nature of white and blue-green lighting seems to contribute to the reduction of visual fatigue over long periods of use.

Another important factor to consider is the effect color has on visual resolution, which relates directly to the visibility of small details within the cockpit. Figure 1 shows the smallest resolvable grating (half cycle in arc minutes) as 0.55 for red,

0.476 for white, and 0.466 for green, which is an operationally non-significant difference. The crew members' ability to resolve the relatively large lettering, pointers, scales, etc., is not effected, though the appearance of color coded markings, flags, or maps may be changed when viewed under various colors. Fine detail in maps would be more visible under white and green illumination.
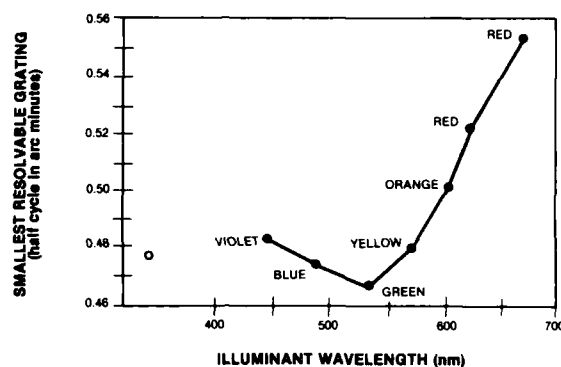

Figure 1. Visual acuity and illuminant wavelength.

The specification of color has undergone numerous changes. An early color matching scheme was devised by Munsell, which is still in use today. It consists of a large set of standardized color chips. Matching of a test sample to the chips was performed under the same illuminant. The drawbacks of this system were that matching varied from observer to observer and that it was a slow process to be performed routinely.

In 1931, the International Commission on Illumination, or Commission Internationale de l'Eclairage (CIE), devised a method to specify color matching that used the actual physical measurement of the spectral energy distribution (SED) curve instead of through subjective visual methods such as that used by the Munsell system. The SED curve is the relative energy output of a filtered or unfiltered light source plotted as a function of wavelength. The CIE system is based on the trivariance of vision, which is the physiological fact that any monochromatic light, is equivalent to the algebraic sum of suitable amounts of three reference lights or primaries. The actual chromaticity is determined by calculating the amounts of the three primaries required by a standard observer to obtain a visual match.

Figure 2 shows the spectral tristimulus values for the 1931 standard observer. Note that the $\bar{y}$ curve is the photopic curve, which is the subjective human visual response to light as a function of wavelength, or color. The $\bar{x}$ and $\bar{z}$ primaries do not physically exist, but were formulated to avoid negative colors.
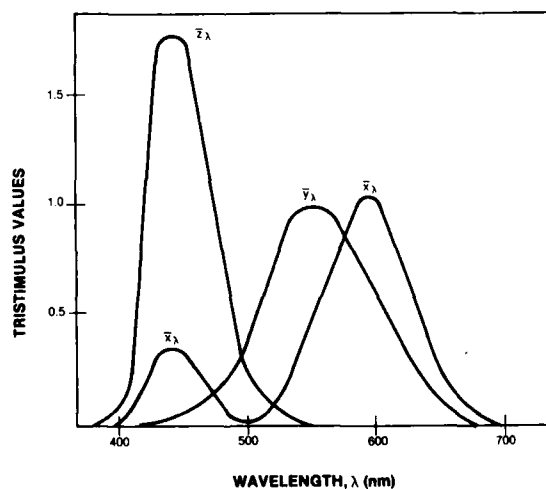

Figure 2. Spectral tristimulus values for the 1931 standard observer.

To calculate the CIE color coordinates, each tristimulus curve (Figure 2) is individually multiplied by the measured SED curve of the sample under consideration, and then integrated over wavelength, the resultant values of which are denoted by X, Y, and Z. Using these values, Equation 1 shows how the chromaticity coordinates x, y, and z are calculated. This procedure normalizes the chromaticity values so that x + y + z = 1.

$$x = \frac{X}{X + Y + Z}; \quad y = \frac{Y}{X + Y + Z}; \quad z = \frac{Z}{X + Y + Z} \tag{1}$$

Figure 3 shows the 1931 CIE chromaticity diagram. There are several features that should be noted. Since the coordinates sum to one, typically, only the x and y values are plotted, the z value being determined by the others (two degrees of freedom). The upside down u-shaped part of the curve represents the 100% saturated, pure spectral colors, which are defined by a single wavelength, as labeled. This curved line is derived by taking the $\bar{x}$, $\bar{y}$, and $\bar{z}$ tristimulus values for each separate wavelength of the standard observer (Figure 2), and calculating the x, y, and z chromaticity coordinates using Equation 1, where $\bar{x}$, $\bar{y}$, and $\bar{z}$ are substituted for X, Y, and Z respectively. Another feature of the diagram is that the colors become pastel, or desaturate, toward the center until they are white. The 1931 CIE color space can only show if two colors match. Differences between two points are nonuniform with respect to human vision. Tolerances found about a point (e.g., the square box shown is x = 0.25 ± 0.05, y = 0.55 ± 0.05), such as those found in some military specifications, are misleading due to the nonuniformity of the 1931 color space.
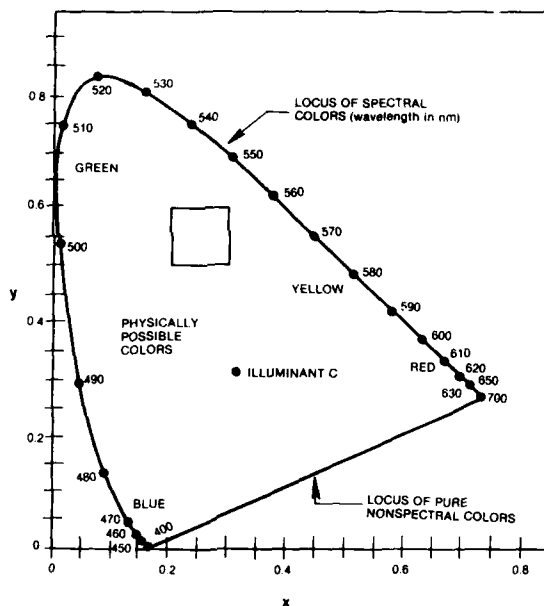

Figure 3. 1931 CIE chromaticity diagram.

The nonuniformity of the 1931 color space was investigated by MacAdam (1942). He measured the adjustment precision for color matching (made by one observer) at relatively high luminances. Figure 4 shows the results, the best fit of the data being ellipses. A common error when interpreting the data from this figure is that the axes of the ellipses are typically drawn ten times the size of the standard deviation of the actual data. MacAdam estimated that the minimum detectable chromaticity difference is three times the standard deviation. Note the nonuniformity among t e different color regions.
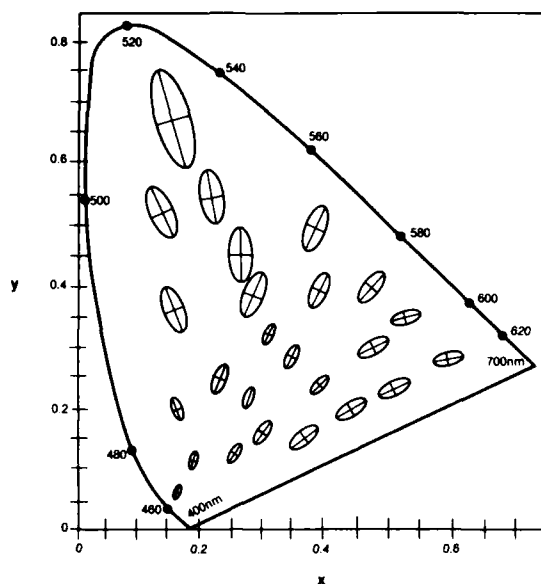
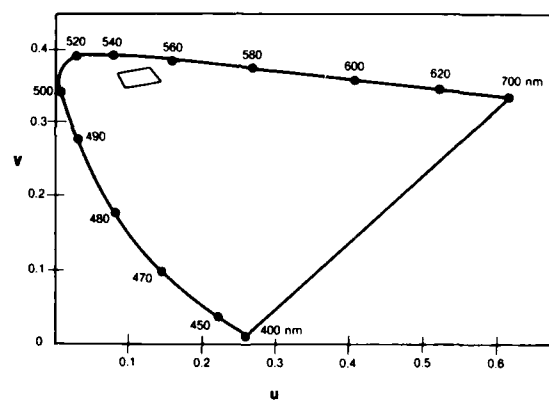Figure 4.   MacAdam's ellipses on 1931 CIE diagram.
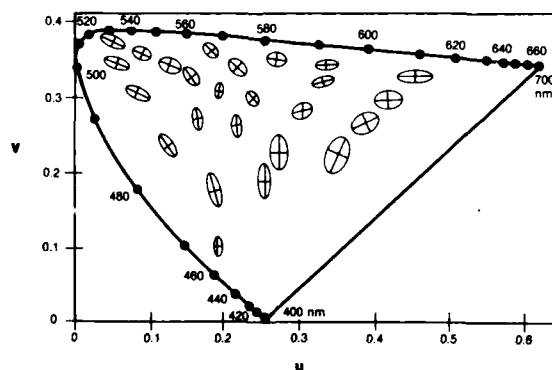

Figure 5.   1960 UCS diagram.

Figure 6.   MacAdam's ellipses plotted on 1960 UCS diagram.

In 1960, the Uniform Chromaticity Spacing (UCS), as shown in Figure 5, was adopted in an attempt to make the color space more homogeneous with respect to human visual perception. The chromaticity coordinates were designated u and v. Note the square box from Figure 3 has been plotted on the UCS diagram and it now appears quite different. Figure 6 shows MacAdam's ellipses plotted on the UCS diagram, where again the ellipses are ten times the standard deviation of the actual data. It can be seen that, although it is nonuniform in some regions, it is very good in view of color sensitivity variations among individuals and is a good compromise between accuracy and simplicity. Tolerances about a point would be specified as either a circle or an amorphous area that would be empirically derived.

The mathematical relationship between the CIE and UCS color spaces is defined by Equation 2. The x and y CIE coordinates can be directly converted to u and v UCS coordinates. Modern color measurement equipment already performs these computations. Equation 3 shows how to convert u and v to x and y coordinates, respectively.

$$u = \frac{4x}{-2x +12y +3}; \quad v = \frac{6y}{-2x +12y + 3} \tag{2}$$

$$x = \frac{3u}{2(u + 2 - 4v)}; \quad y = \frac{v}{u + 2 - 4v} \tag{3}$$

In 1976, the UCS diagram was further refined and designated CIE 1976 (u',v') UCS diagram, using u' and v' coordinates. It is shown in Figure 7 with the accompanying equations to convert from 1960 to 1976 space. The mathematical relationship between the 1976 and the 1960 spaces is u' = u and v' = 1.5v. Again, note the change of the tolerance box shape as replotted in the 1976 space.
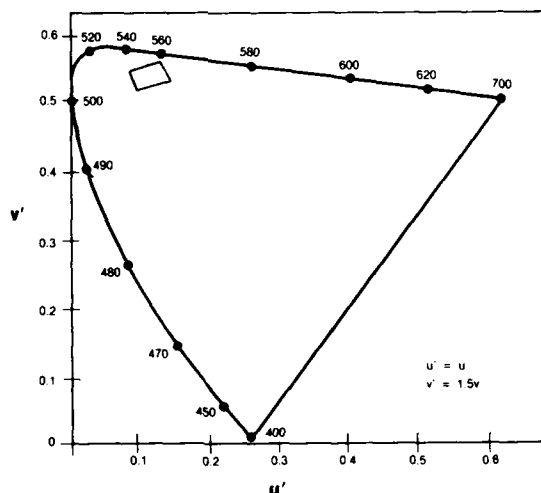

Figure 7. CIE 1976 (u',v') UCS diagram.

Given this background, practical applications using the CIE 1976 (u',v') UCS diagram can now be discussed in some detail. Figure 8 shows the 1931 CIE space with points of blue-green, green, and yellow-green light sources that represent candidates for night vision goggle compatible lighting applications. The distances among the points have little meaning due to the nonuniformity of the space and may be erroneously interpreted as having large perceived color differences. Figure 9 shows the same points plotted in 1976 space. Distances among points are now meaningful with respect to visual perception. The perceived color differences can be predicted to be small.
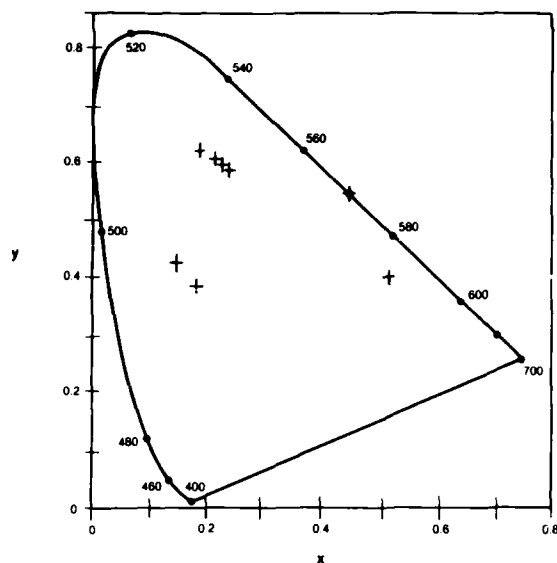
Figure 8. Various greenish colors plotted in CIE space.
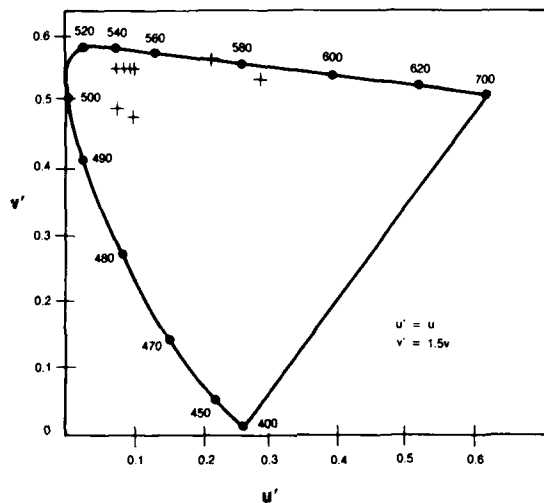
Figure 9. Same colors of Figure 8 replotted on the CIE 1976 (u',v') UCS diagram.

Color specification for aircraft should be defined in the 1976 space, not the 1931 space. The defined chromaticity areas should be based on performance criteria, not arbitrary tolerances or wholly aesthetic qualities. The limits should be empirically derived, if possible. For example, many specifications require one ft-L maximum luminance with chromaticity tolerances in 1931 CIE space. However, as was shown earlier, operational instrument luminances typically range from 0.1 to 0.001 ft-L. Figure 10 shows the perceived desaturation of hue (color) as a function of luminance (Hunt, 1953) in 1976 space. The outermost points (#1) are the actual measured chromaticity of variously colored lights at 314 ft-L. As the luminances of the lights were reduced

(points #2 through #5 were 19, 2.4, 0.8 and 0.09 ft-L, respectively), their perceived hue desaturated. While these colors appeared very different at the higher luminances, at operational levels they desaturated and appeared more similar. An additional factor is that many basic color experiments, such as the one constructed to derive the data in Figure 10, use standard and test color patches that are visually adjacent. Very small color differences are easily detected using this method. Lights in aircraft are usually separated by some small distance, which also makes the detection of the (perceived) desaturated light's color differences even more difficult. Given the low operational luminances and physically separated signals found in cockpits, some specified color tolerences may be too restrictive.
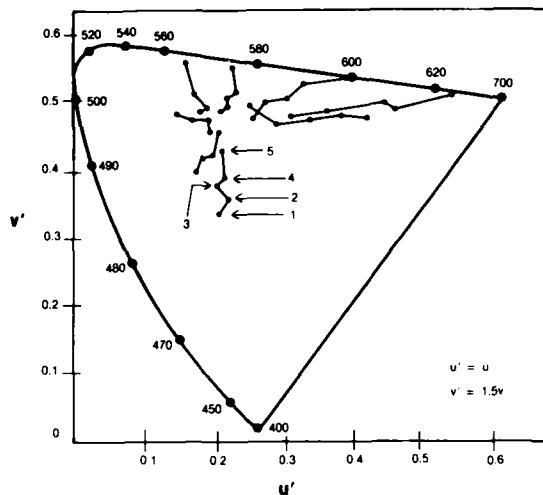

Figure 10. Perceived desaturation of hue as a function of luminance.

There are other performance criteria to be considered when specifying color tolerances. Variables that affect performance include: operational luminances, proximity of light signals, ambient lighting, chromaticity, and color coding. For empirical investigations, error rates, response times, fatigue, and workload may be used as evaluation criteria.

It has been shown that the 1931 CIE space is for matching colors only. The CIE 1976 (u',v') UCS diagram is more appropriate when specifying color tolerances. Color specifications and tolerances should be based on performance criteria, whenever possible.

Returning to other subsystem lighting requirements, illuminated pushbuttons have to be visible in high ambient illumination, as do warning, caution, and advisory signals. Several years ago, one hundred ft-L was common. Two to three hundred ft-L are required to be clearly visible. These signal lights are typically dimmed to 15±5 ft-L, which is still quite bright in a darkened cockpit. At night, the F-15 maintains the master warning and master caution lights at about 10 ft-L but employs continuous dimming for all other annunciator lights, down to an absolute minimum of 0.05 ft-L. The annunciator lights cannot be dimmed to extinction. Pilots report that this system works very well at night, especially when some of the signals (e.g., landing gear down) remain lit for relatively long periods of time.

Floodlights are used for pre- and post-flight checks, as an emergency backup system in case of a primary lighting system failure, as supplemental or fill lighting to the primary lighting, and during lightning storms to diminish the deleterious visual effects of the bright flashes of light. Aircraft that may be exposed to nuclear flashes have the floodlight system coupled to the automatic thermal protective closure systems for anti-dazzle. The highest floodlight illumination on the main instrument panel should be at least 100 ft candles and 150 ft candles for nuclear flashblindness protected pilots. The higher illumination is needed because, even though the protective closure system (PLZT) has been activated, it is not instantaneous and the pilot may still be exposed to a very bright flash. The higher cockpit illumination is needed to maintain instrument readability. Floodlighting must be continuously dimmable to very low levels before extinguishing. They must also have good, uniform coverage of the entire suite with a minimization of direct or reflected windscreen glare and few shadows on or within the instruments.

Head-up displays (HUDs) are specialized pieces of equipment, designed for specific aircraft and missions. To that extent, only the F-16 A/B and C/D HUDs will be overviewed. The F-16 A/B HUD has a total field of view (FOV) of 20 degrees. The stroke-written images must be visible against a background illumination of 10,000 ft candles

and have an average luminance of the symbol lines of 1,600 ft-L minimum. Contrast ratio is a minimum of 1.2:1 which is a 0.2 contrast. Note that achievable contrast for this display is much lower than that of painted instruments. Dimming is controlled by the cathode-ray tube (CRT) brightness control which is continuously variable. The control of the luminance is logarithmic so the subjective impression of the brightness changes is linear. A broad range of luminances is achieved by the insertion of a night filter into the optical path of the HUD. The CRT utilizes a green P-1 phosphor.

The F-16 C/D HUD differs from the A/B in that it has 25 degrees FOV, and it can display a raster generated image, like a television, with simultaneously displayed stroke-written symbology. The raster mode is used to display sensor imagery such as forward-looking infrared. The luminance and contrast for the stroke-written symbology is the same as the A/B HUD. In the raster mode, the HUD is capable of six shades of gray against a 30 ft-L background. Since this HUD has a raster capability, its night brightness mode is more difficult to achieve. It must be able to clearly and uniformly display information while not obscuring outside vision of a dimly lit scene such as a horizon lighted only by moonlight. The veiling, blank areas of the raster, cannot exceed 0.02 ft-L. This HUD also uses a green P-1 phosphor.

The F-16 C/D also utilizes a CRT multifunction display (MFD) that can display both 525 and 875 line vertical resolution. It is capable of 3,000 ft-L output, but is attenuated to 1,000 ft-L by the contrast enhancement filter. Brightness and contrast compensation are automatically changed as a function of ambient illumination down to 15 ft candles. The unit also has manual brightness and contrast controls that provide the pilot additional control over the display. Symbology brightness has a separate, continuous control. The F-16 A/B uses a radar/electro-optical CRT display that has a similar image display capability as the MFD described above, with the exception that its peak output luminance is 2,000 ft-L. Both displays utilize a P-43 phosphor.

NIGHT VISION GOGGLE COMPATIBLE LIGHTING

To this point, general and specific cockpit lighting characteristics and requirements for high performance aircraft have been described. A special area within this subject is night vision goggle compatible (NVGC) lighting. Night vision goggles (NVGs) are being used with greater frequency for night missions. NVGs amplify near infrared (IR) energy in order to enable the pilot to see at night. However, the standard lighting in aircraft emits large amounts of IR which interferes with the proper functioning of the goggles. The remainder of this paper will describe the basic NVG, light source characteristics, lighting specification, and the methods that are used to achieve NVG compatibility in the cockpit.

NVGs are electro-optical devices that detect, amplify, and display on a small green phosphor screen, visible and near infrared energy from dimly illuminated nighttime scenes. They look like small binoculars and can be worn on the aviator's helmet. NVGs utilize an image intensifier tube. As shown in Figure 11, the image intensifier tube has three basic elements: a photocathode for conversion of photons to electrons, a microchannel plate for electron multiplication, and a phosphor coating for conversion of electron energy back to photons for viewing. The output window is a bundle of fiber optics constructed with a 180 degree twist to yield a right-side-up image for viewing. The goggles have a FOV of 40 degrees and their resolution, in terms of human visual acuity, is about 2 arcminutes or 20/40. NVGs have an automatic gain feature that adjusts the sensitivity of the goggles to minimize bloom or wash out of the image.
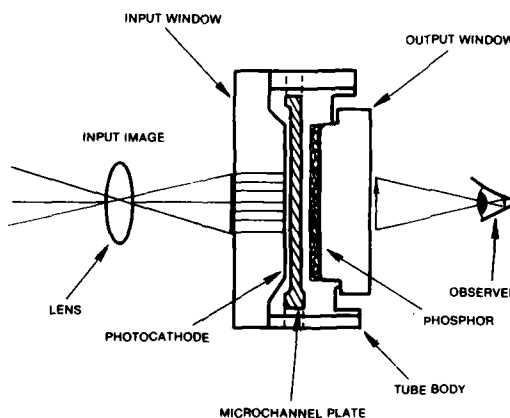

Figure 11. Image intensifier tube.

There are several types of NVGs currently in use (see Verona, AGARD-CP-379). They differ in their optics, spectral sensitivities, and packaging. The Army's original PVS-5 goggles were either strapped to the helmet or worn on the face, but peripheral vision was restricted. The PVS-5 goggles were then modified by cutting away the lower part for use in rotary and fixed-wing aircraft. It must be noted that aviators look through the goggles at outside scenes and underneath them, using direct, unaided vision (as represented by the photopic curve, Figure 12) to look at their instrumentation. The modified version is designated ANVIS-5 and both types used generation 2 image intensifier tubes, employing a multi-alkali photocathode. Another version with different optics and having greater sensitivity is designated generation 2-plus. Third generation intensifier tubes use a gallium arsenide photocathode, have even greater gain, and are more sensitive to IR energy as available from the night-sky spectral irradiance. Figure 12 shows the relative sensitivities of generation 2 and 3 NVGs, as a function of wavelength. Note the generation 3's greater sensitivity and shift toward the IR. The figure also shows the energy from the night-sky spectral irradiance, which is predominantly in the IR. Figure 12 also shows the spectral energy output of a standard white incandescent lamp. It can be seen that large amounts of energy are in the same region of the goggle's sensitivity. This IR pollution causes glare and reflects off the inside of the windscreen. The autogain adjusts to the higher input of the IR reflections, making it impossible to see the outside, lower energy scene.

Figure 12. The photopic curve, generation 2 and 3 sensitivities, incandescent lamp curve, and night-sky spectral irradiance.
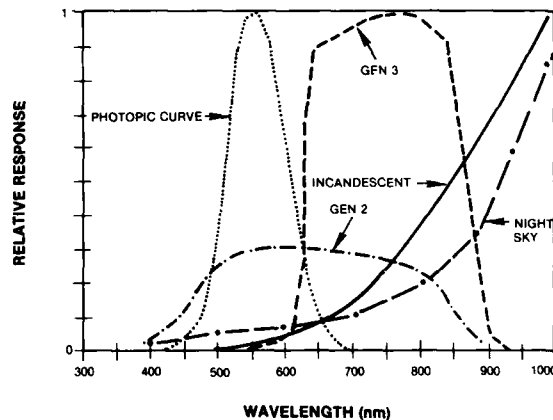
NVG compatibility is achieved by removing the IR energy from as many light sources as possible. It should be pointed out that, since generation 2 goggles use part of the visible spectrum as well as the IR, 100% NVG compatibility is difficult to achieve. However, filtering the IR energy from the lighting helps a great deal for generation 2 goggles. Filters are often placed on the goggles themselves, but performance is reduced. Generation 2 NVGs require extra filtering but generation 3 goggles have incorporated a minus-blue filter that blocks out visible light below 580 nanometers. Complete NVG compatibility is achieved with generation 3 goggles when the SED of the cockpit lighting does not overlap the goggle sensitivity. The cockpit lighting must still be visible to the unaided eye. The required luminance levels, as previously described, apply to a NVGC lighted cockpit. Removal of the red component of white light results in the characteristic blue-green colored NVGC cockpit. If the outside scene is bright, the NVGs will act as a relatively high (several ft-L) adaptive field, requiring slightly higher average instrument luminance settings by the pilot. A NVGC lighted cockpit, as seen through NVGs, has a greatly reduced IR signature from both inside and outside of the aircraft.

NVGC LIGHTING SPECIFICATION

The current military specification for NVGC lighting in aircraft is MIL-L-85762A. It is a comprehensive document that addresses lighting subsystems found within most aircraft. It has established the dimmed, nighttime luminance and illuminance levels at which an article is to be tested. Chromaticities for NVGC green, yellow, and red have been established in 1931 CIE color space. Measurement techniques and equations have been detailed to measure and calculate the luminances, illuminances, contrasts (with compensating multipliers), spectral energy distributions, and chromaticity coordinates of the lighting subsystems in question. The bottom line is that no cockpit light energy (for instrumentation at 0.1 ft-L) can exceed 1.7×10^{-10} watts/steradian-cm^2, which is the ANVIS-weighted radiance reflected by tree bark illuminated by starlight (see Breitmaier and Reetz, AGARD-CP-379). This value is believed to be the practical lower limit to conduct maneuvers and any cockpit lighting that exceeds this might cause interference with the goggles. It is a stringent criterion to meet and lights that are not in the goggle's FOV are penalized. Actual measurement of such low energy levels is also a practical problem, and requires specialized equipment.

Night vision goggle compatibility is defined as lighting that is sufficient for the unaided eye to read instruments and displays and, simultaneously, does not interfere with the operation of the NVGs in viewing scenes outside of the cockpit. Until

recently, there were no NVGC light specifications to use as guidelines for the manu-
facture of the needed lighting equipment. To this end, a framework and approach were
developed by this laboratory (see Genco, AGARD-CP-379) to establish a more quantitative
description of NVGC lighting. There are two broad areas of NVGC lighting that must be
considered. The effects on direct, unaided vision and the effects on NVG performance.

The lighting effects on vision can be divided into four desirable attributes. (1)
There must be sufficient light to read the instrumentation and displays. (2) It is
preferred that color and intensity be relatively (perceptively) uniform. (3) If
possible, retain color coding and cueing. (4) The lighting must be suitable for non-
NVG night flights.

Item 1 is a hard requirement, since proper use of NVGs involves looking through
the goggles to see outside and underneath them to directly view the instruments and
displays. However, one should not immediately dismiss the possibility of eliminating
(turning off) all lights to achieve NVG compatibility.

Item 2 is not a hard requirement, but is highly desirable. The easiest approach
to specifying this characteristic is to designate an acceptable area of CIE color
space. However, as stated earlier, CIE space is nonuniform with respect to visual
sensation and color perception is greatly reduced for the lighting levels of concern
for night operations. The first fact implies that the allowed coordinates, if
expressed in 1931 CIE space, will not correspond to some symmetric geometric shapes
(i.e., square or circle). As discussed earlier, it is more appropriate to specify a
circular area in the CIE 1976 space since it relates more closely to human visual color
discrimination. The second fact implies that the area in 1976 or 1931 space can be
relatively large because it's just not possible to easily perceive color differences at
these low light levels. The exact area in color space that is allowable is subject to
discussion.

Item 3 is highly preferable, but again, not required. If the location and light
level of indicator lights are carefully established, it is possible to retain the use
of red and yellow light (limited uses) without affecting NVG operation. The present
(1931 CIE) specification of these colors for cockpit use is probably acceptable.

Item 4 should probably be regarded as a hard requirement. It may be accomplished
by providing auxiliary lighting for normal night flight which can be totally turned off
for NVG flight.

The NVGs can be adversely affected in several ways: a NVG shutdown due to light
sources in the field of view, severe contrast loss due to reflections of light sources
in the windscreens, and loss of contrast due to flare (light scattering within objec-
tive lens of NVGs due to cockpit lighting). As a result of these effects, it is
proposed that the lighting be considered in three categories. These three categories
are divided according to the effect of the lighting on the NVGs. Category 1 is for
lights that appear directly in the FOV of the NVG when viewing outside the cockpit.
Category 2 is for light sources that are located so as to directly reflect in the
windscreen. Category 3 is for light sources that are in the cockpit, generally adding
to the IR pollution (neither Category 1 nor Category 2). To assess the level of
compatibility of each of these light sources, it is necessary to calculate (or measure)
the relative vision sensitive light compared to NVG sensitive light. This is done by
calculating the compatibility ratio (C_R). The C_R is measured by calculating the ratio
between vision sensitive light and NVG sensitive light as shown in Equations 4,5,6.
Category 1, as depicted in Figure 13, is probably the most severe and will require the
highest compatibility ratio. Category 2 (Figure 14) is also of considerable concern,
but since the windscreen only reflects 8-
10% of the light incident on it, the
compatibility ratio for Category 2
sources may be somewhat less than
Category 1. Category 3 (Figure 15) is
the least severe since it represents
general IR pollution in the cockpit.
Note the yellow and red indicator lights
should be situated so they fall into
Category 3 in order to be NVG compatible.
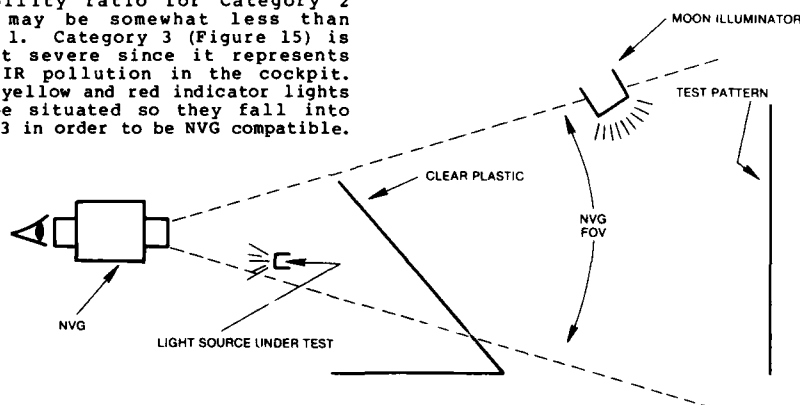
Figure 13. Category 1 lighting/goggle geometry.
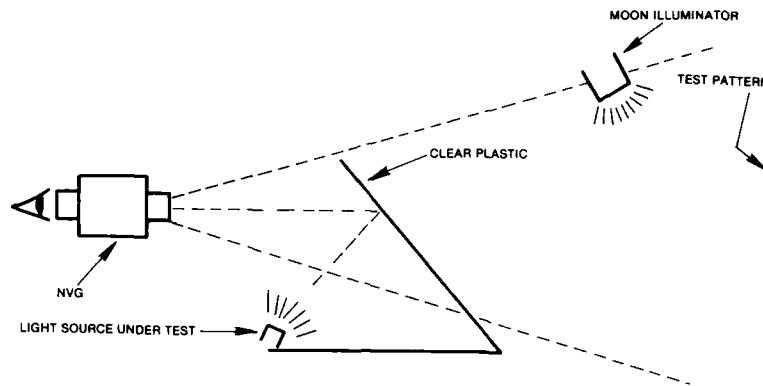
Figure 14. Category 2 lighting/goggle geometry.
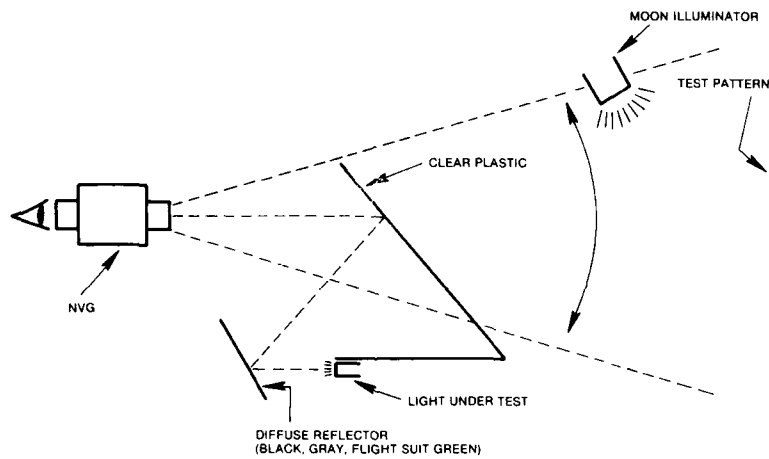
Figure 15. Category 3 lighting/goggle geometry.

Vision calculation:

$$\text{LUMINANCE} = L_V = 680 \int_{\lambda = 400 \text{ nm}}^{\lambda = 700 \text{ nm}} S(\lambda)F(\lambda)V(\lambda)d\lambda \tag{4}$$

where: $S(\lambda)$ = Spectral distribution of light source (Watts/cm^2-STR-μm)

$F(\lambda)$ = Filter spectral transmissivity (no units)

$V(\lambda)$ = Visual spectral sensitivity (no units)

λ = wavelength

NVG calculation:

$$\text{RADIANCE} = R_{NVG} = K \int_{\lambda = 400 \text{ nm}}^{\lambda = 1000 \text{ nm}} S(\lambda)F(\lambda)G(\lambda)d\lambda \tag{5}$$

where: $G(\lambda)$ = NVG spectral sensitivity
K = Proportionality constant (TBD)

Compatibility Ratio (C_R) calculation:

$$C_R = \frac{L_V}{R_{NVG}} \qquad\qquad (6)$$

Equation 4 calculates the luminance the observer will see taking into consideration the spectral distribution of the light source, the filter's spectral transmissivity, the visual system's sensitivity, and integrating over the visible spectrum (400 to 700 nm). The calculated luminance value (L_V) forms the numerator in Equation 6. Equation 5 calculates the radiance amplified by the goggles by accounting for the spectral distribution of the light, the filter's spectral transmissivity, the goggle's sensitivity, and integrating over the visible and goggle spectrum (400 to 1000 nm). The calculated radiance (R_{NVG}) forms the denominator of Equation 6. The higher the compatibility ratio (C_R; Equation 6), the more stringent the requirement. Thus, Category 1 lights would have to meet or exceed a higher C_R than a Category 2 light. A Category 2, C_R would be higher than a Category 3, C_R.

The weighting of light sources according to their geometric relationship to the FOV of the NVGs and their subsequent effect on the compatibility, as calculated by the above equations, form a conceptual framework and predictive model for NVGC. Additional work is required to validate the model; however, the NVGC lighting specification (MIL-L-85762A) is currently undergoing revision that takes into account (through weighting) the geometric location of color CRTs.

NVGC LIGHTING TECHNIQUES

There are numerous methods that can be used to control the IR within the cockpit (see Task and Griffin, December 1982). Primary methods are light source selection and filtering techniques. Figure 16 shows the SED curves for unfiltered and filtered incandescent lamps, electroluminescent (EL) panels, and light-emitting diodes (LEDs) in relation to generation 3 NVG sensitivity. Incandescent lamps need to be filtered because of their high IR output. Incandescent lamps are blackbody radiators, thus their output varies as a function of temperature. EL is a cold light source that is essentially a capacitor with a CRT phosphor coating that glows when excited by an alternating electrical current. Figure 17 shows an exploded diagram of an EL lamp. As can be seen in Figure 16, green EL lamps emit very little, if any, IR energy. Certain LED colors also work well for these applications, as shown in the same figure.
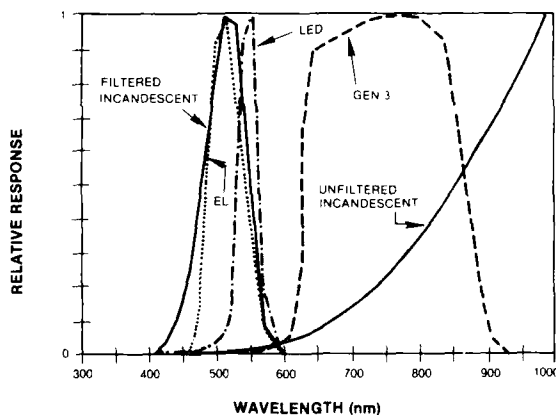

Figure 16. SED curves for unfiltered and filtered incandescent, EL, and LED light sources shown in relation to generation 3 NVG sensitivity.

TOP ACLAR

DESICCANT

FRONT LEAD

BUS BAR

TRANSPARENT ELECTRODE

PHOSPHOR

FOIL
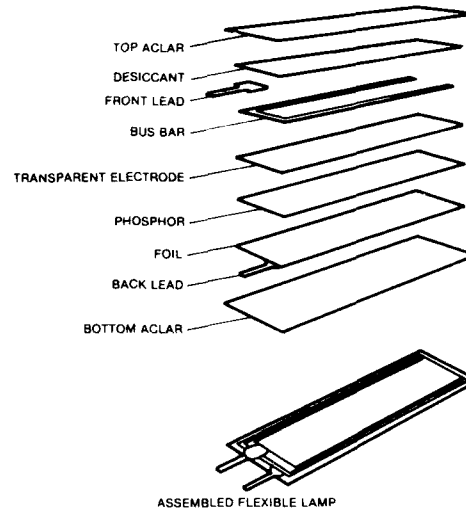
BACK LEAD

BOTTOM ACLAR

ASSEMBLED FLEXIBLE LAMP

Figure 17. EL lamp construction.

In addition to source type and filtering, other methods are available to make a cockpit goggle compatible. Reflections on the inside of the windscreen can be controlled through the use of microlouver material, an extended glare shield, and black flight suits. Microlouver (ML) is a 1/16 inch plastic film developed by 3M Corporation that has numerous parallel baffles at a fixed angle, very similar to venetian blinds but very small and cast in plastic. By varying the baffle spacing and tilt, the fan of light that is allowed through the material can be controlled. ML comes in three fan widths of 48, 60, and 90 degrees and a specified tilt angle with respect to the vertical. Fan and tilt angles can be appropriately chosen to direct light from a display or light toward the pilot and away from the windscreen to reduce reflections. ML also reduces the amount of light, as well as resolution of detail, to the observer. While ML effectively controls visible light, it was found to be partially transparent to IR. An IR-blocking plastic film must be used over the display or light. With this modification, ML material can be successfully used in NVGC lighted cockpits.

Reflected glare can sometimes be controlled by extending the glare shield to reduce glow from the main instrument lights. The extension may also provide additional space to mount NVGC lights. A glare shield extension can be made adjustable, so different pilots can pull it in or out as needed. Care must be taken to not hamper the crew's escape pathways (through windows) or impinge on the ejection seat envelope of aircraft so equipped. Black, nomex flight suits are also desirable for use in NVGC cockpits to reduce reflections, as would a black helmet. Black suits appear to be more effective in partially modified cockpits where there is still some IR pollution being reflected. Fully modified cockpits have virtually no IR to be reflected, ' .ough external ambient energy could be reflected.

Aircraft can be modified to varying degrees of NVG compatibility, depending on the time and money available. A quick-fix modification is fast and low cost, but there is usually some reduction in visibility of the direct view instrumentation with some residual IR pollution. A full-up modification is costly and time consuming, however, it approximates state of the art NVGC lighting where there is essentially no IR and direct view visibility is excellent.

A quick-fix modification can be as simple as turning off the entire lighting system and illuminating the cockpit with filtered floodlights. Black tape can be used to cover indicator lights. Under the glare shield, incandescent lamps can be directly replaced with green LEDs. Various displays and lights can be fitted with Schott blue-green glass, Wamco glass, or Glendale green plastic filters that can be snapped on and off as needed. NVGC external light wedges, or bezels (see Figure 18), are sometimes mounted over the most important instruments.
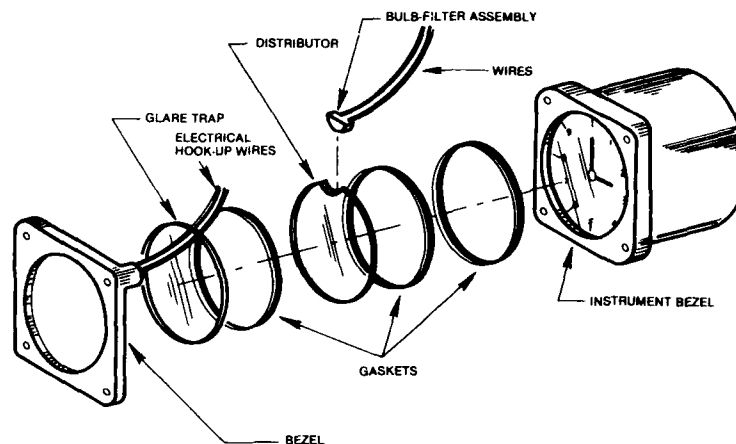
Figure 18. External light wedge (bezel) construction.

A full-up modification is very extensive. External light bezels (Figure 18) are placed over all instruments except the ones that are illuminated with small individual post (flood) lights. The post light caps are filtered. All floodlights and work lights are filtered. Green advisory and yellow caution annunciators are filtered to blue-green. Red warning lights are changed to NVGC yellow. All panels are replaced with NVGC green. Depending on the panel type, the light source is either filtered incandescent or electroluminescent. CRTs and moving map displays, if present, are covered with filters. Aircraft CRTs are often green P-43 phosphors that have a small red component that, if necessary, is easily filtered. Glass filters are best, due to their higher degree of stability under the extreme environmental conditions that are so often encountered.

CRTs used in radar, MFDs, and moving maps can be filtered to achieve NVG compatibility. HUDs usually have green, P-43 phosphor CRTs in order to obtain maximum brightness in the daytime. These types of HUDs can usually be turned down very low at night and directly viewed through the goggles. Focusing is no problem since the HUD is collimated, and the NVGs are focused at optical infinity to view the outside.

For aircraft that do not have HUDs, it is desirable to have flight information displayed while maintaining a head-up, out-of-the-cockpit position. This laboratory has developed a retrofit NVG/HUD system (see Genco, AGARD-CP-379) to perform this task. Figure 19 shows the NVG/HUD layout. The flight instrument raw signal information is collected by the aircraft's signal processing computer, converted into properly formatted data, and transmitted to the display unit. The display unit converts the data to symbols and displays them on a red CRT. Red is used so that the symbols are visible through the goggles. The symbology display is reflected from a front surface mirror to a relay lens which focuses the image onto a flexible fiber optic bundle. The bundle transmits the image to the NVG where a collimating lens projects the symbol image to optical infinity. This image is then reflected from a beam splitter into one ocular of the NVGs. The observer views the image of the HUD symbols superimposed over the outside view.
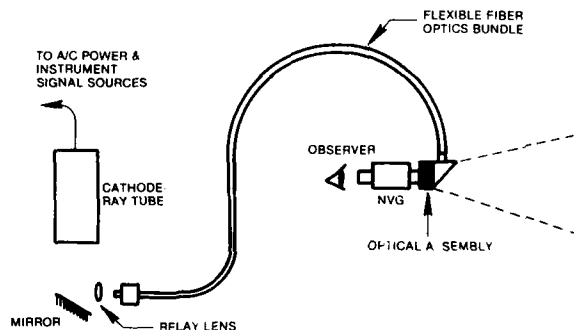

Figure 19. NVG/HUD Configuration.

7-16

This paper has described the night lighting requirements for high performance aircraft cockpits. It also overviewed NVG characteristics and defined NVG compatibility for cockpit lighting. Methods of achieving NVG compatibility were shown as represented by quick-fix and full-up modifications. These modifications greatly enhance the performance of NVGs that help the pilot to successfully complete his mission.

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DISPLAY SYSTEM IMAGE QUALITY

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SUMMARY

High performance aircraft employ several types of display systems including panel-mounted cathode-ray tube (CRT) displays, head-up displays (HUDs) and helmet-mounted displays (HMDs). These may be used to produce imagery from onboard sensors or to provide information in a symbolic format. There are a number of parameters that are used to characterize these displays such as resolution, contrast ratio, luminance, number of gray shades, line rate, interlace ratio, bandwidth, and modulation transfer function. In the case of the HUDs and HMDs, there are other parameters that further describe the display such as distortion, transmittance, field of view, exit pupil diameter, vergence, and field curvature. This paper will describe these systems, the measurement of various parameters, and how they affect the quality of the display system. In addition, methods will be presented that combine the display parameters with human visual system characteristics to produce image quality metrics that are related to operator performance.

CRTs

Panel-mounted displays can be either monochromatic or color cathode-ray tubes (CRTs) such as those used in television, solid-state liquid crystal displays (LCDs), or even thin-filmed electroluminescent. For this discussion, only CRTs will be described in detail, though most characteristics and measurements are the same or can be extrapolated to their solid state counterparts.

A monochromatic CRT is basically a glass vacuum tube that has an electron gun on one side and a curved or flat side that is coated with some type of phosphor, which is usually (but with exceptions) located on the opposite side. The electrons are accelerated toward the phosphor by the anode potential which is the voltage between the electron gun beam and the phosphor screen. There are numerous phosphor types (Westinghouse, 1972). Phosphor characteristics vary as to their chemical composition, phosphorescent color, spectral energy distribution (SED), and persistence. For example, P-43 is a yellow-green phosphor with a 543 nanometers (nm) peak wavelength and a medium class persistence, making it suitable for surveillance radar used in bright sunlight.

The different luminance levels of the picture are formed by modulating the electron-gun beam. The amount of emitted light is proportional to the number and energy of electrons striking the phosphor. The beam is magnetically focused to a very small spot on the phosphor screen. It is horizontally and vertically deflected by electro-magnetic coils or electro-static plates, which are synchronized to a camera or other source such as a computer. The pattern in which the beam is deflected is termed the raster. A standard raster is formed by first painting every other horizontal line to form one-half the picture (or field) and then the second half is filled in. The persistence of the phosphor and the raster refresh rate are chosen to minimize perceived flicker. Alternating fields having this structure are designated as having a 2:1 interlace, but other interlace ratios such as 1:1 or 4:1 are used for various applications. The two fields form a frame and the standard frame rate (in the US) is 30 hertz. The vertical resolution is fixed by the electron beam size and raster structure. Standard television (in the US) has 525 horizontal lines but approximately 15% are lost to beam retrace time, so only 450 lines are actually displayed. From 875 to over 2000 horizontal lines are used for the higher resolution applications. Horizontal resolution is limited by the beam spot size, phosphor type, and bandwidth of the electronics. The beam excites the phosphor and creates a spot with a near Gaussian luminance distribution. The spot size is typically around 8 mils at the 50% luminance point for larger CRTs and down to tenths of a mil for miniature CRTs.

A stroke-type CRT display differs from a standard display in that there is no fixed raster structure and, therefore, no complex pictures or imagery can be presented. Instead, lines and symbols are written directly on the phosphor under the control of an electronic symbol generator. Since there is no raster, stroke-written symbology appears continuous and the higher luminous outputs can be used for higher ambient, daytime applications. However, there is an upper limit as to the total number of symbols that can be simultaneously displayed. Some specialized CRTs can mix raster and stroke to provide an image with overlaid symbology.

Color CRTs are an extension of the monochromatic raster type display. Instead of one electron gun, there are three guns, one for each of the basic colors of red, green, and blue. Each color is modulated for its particular amount of information and is shot through a finely perforated metal plate termed aperture or shadow mask, which is

located near and parallel to the phosphor screen. The shadow mask keeps the proper beam aligned with its corresponding phosphor. The screen has clusters of red, green, and blue phosphor dots, called triads. The triad is the basic resolution unit of a color screen. Each phosphor dot and triad may have a black surround. This black matrix acts to reduce the reflection of ambient light from the display face, giving the display better contrast. The structure of the triad is sometimes constructed of vertical stripes instead of dots. Monochromatic CRT phosphors have no discrete structure. Their vertical resolution is dictated by the horizontal raster structure. The horizontal resolution is much higher and is influenced by the electronic bandwidth and spot size. Color CRTs have the discrete, triad structure that strictly limits both vertical and horizontal resolution. Smaller triads produce higher resolution.

The F-16 C/D utilizes a (monochromatic) green, P-43 phosphor, panel-mounted multifunction display (MFD) CRT that can display both 525 and 875 line rasters. It has a very high luminous output of 3000 foot Lamberts (ft-L), which is attenuated to 1000 ft-L by a contrast enhancement filter. The F-16 A/B uses a panel-mounted P-43 type CRT to display radar and electro-optical imagery. Its resolution is similar to the MFD, but has a slightly lower peak output luminance of 2000 ft-L.

HUDs

Another type of display that uses a CRT is the modern HUD. This device has evolved from the optical gunsights of many years ago. This type of sight had an illuminated reticle or crosshairs reflected off a partially silvered mirror (or combiner), which was mounted directly in front of the pilot above the glare shield. Its superior aiming performance was due to the crosshairs being focused at optical infinity. This collimated image had parallel light rays the same as the light from the distant targct, thus, parallax error was greatly reduced and aiming accuracy was increased. Parallax is the misalignment of two (or more) images because they appear at different optical distances. HUDs are essentially optical gunsights that use CRTs in place of the reticle to display information.

The basic components of a HUD (see Figure 1) are the image source, which is usually a CRT (but can also be a liquid crystal display), a mirror to fold the optical path, a collimating lens which focuses the light rays at optical infinity (parallel rays), and a combiner which is partially reflective and transmissive. The combiner reflects the CRT imagery while allowing the outside scene, which is also at optical infinity, to pass through, thereby superimposing both images for the observer. This is an idealized description that ignores the windscreen optical effects. HUD optics can be either nonpupil-forming or pupil-forming. A nonpupil-forming system is like a simple magnifying lens in that, as the observer moves his eye position, different parts of the image become visible. A pupil-forming system (an example being a telescope) has an area in which the entire image is seen as long as the eye is anywhere within the exit pupil area. The image disappears when the eye is outside of this area. The distinguishing factor is that in nonpupil-forming optics, the aperture stop is the simple magnifier. In pupil-forming optics, the exit pupil is the image of the aperture stop of the system as viewed from the image space of the system. Eye (and head) position is less critical for nonpupil-forming systems, but the observer must move around to see all the information. The total field of view (TFOV), expressed in degrees of visual angle, in a pupil-forming system is the same as its instantaneous field of view (IFOV). In nonpupil-forming systems, the IFOV is the same or smaller, but cannot exceed the TFOV. As shown in Figure 2, each eye has a slightly different IFOV which is termed the monocular IFOV. The area seen by both eyes is the binocular IFOV (BIFOV).
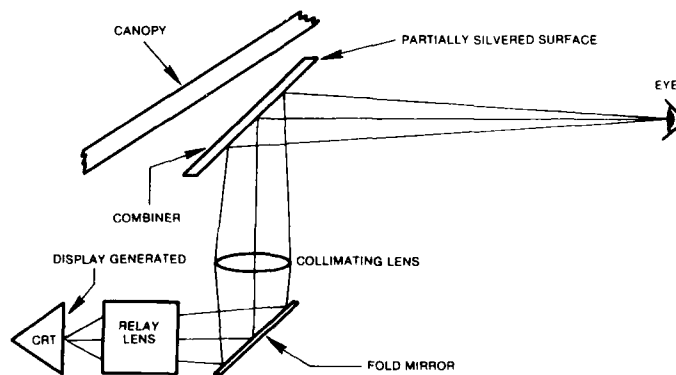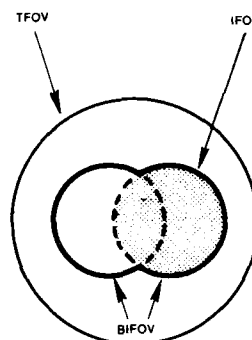

Figure 1. A refractive HUD.

Figure 2. HUD fields of view.

     Pupil and nonpupil-forming systems can be constructed using refractive, diffrac-
tive, reflective, and holographic optical elements. In the refractive system, the
principal converging element is the collimating (refracting) lens. A typical refrac-
tive HUD system is shown in Figure 1. In these systems, the TFOV is always larger than
the IFOV, though the vertical IFOV is usually very close to the vertical TFOV. The
pilot must move his head around to observe all of the information. Binocular vision
facilitates the acquisition of information in the horizontal plane. Referring to
Equation 1, the BIFOV is greater than the IFOV by a factor of (1+2.5/d), where 2.5 is
the average interpupillary spacing of the eyes (in inches) and d is the diameter of the
collimator aperture. The larger the collimator aperture, the less pronounced the
effect. The larger the collimator aperture, the larger the IFOV, but the weight of the
lens increases quickly. A 25% increase in the IFOV may cause a 100% weight increase in
refractive HUD optics.

$$BIFOV = IFOV \ (1 + 2.5/d) \qquad\qquad (1)$$

     In order to increase the IFOV without incurring a severe weight penalty, reflec-
tive optics can be utilized. As shown in Figure 3. the principal optical element is a
curved combiner which may also serve as the final collimating element. The IFOV is
increased by increasing the size of the collimator or reducing the collimator to eye
distance. If the system is designed to be pupil-forming, the IFOV and TFOV are the
same. All information is visible as long as at least one eye is within the exit pupil.
Figure 3 is a pupil-forming system. Reflective systems have been constructed up to 40
degrees which weigh up to 30 pounds. The larger combiners have optical aberrations
that are usually corrected by relay lenses located between the CRT and the folding
mirror. Combiners must have low, see-through, refractive errors and low reflective
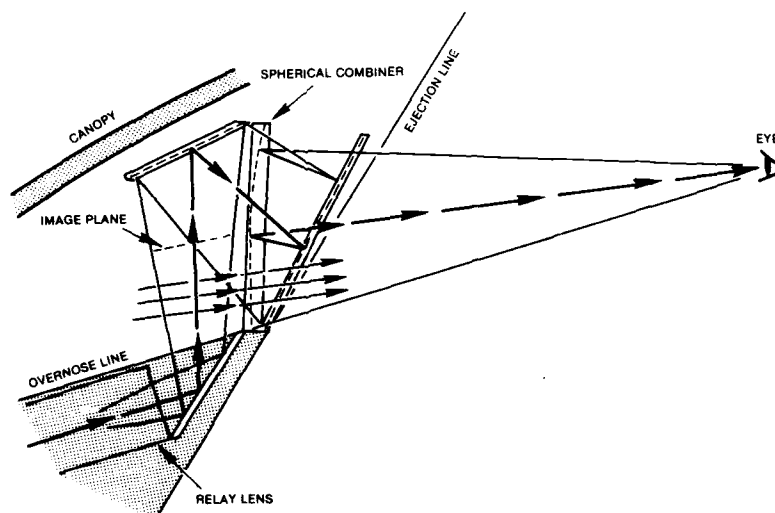aberrations. The F-16 A/B and C/D models use nonpupil-forming, refractive HUDs.

Figure 3. A reflective, pupil-forming HUD.

HUD performance may be further improved through the use of diffractive optics. Diffractive optics allow a more efficient use of the CRT light while maintaining good see-through transmissivity of the combiner. A diffractive element, which can be produced by several methods, has an interference or fringe pattern recorded within or on top of a substrate material. When light of the proper wavelength falls on this element at the proper angle, the interference pattern reproduces the original spherical wavefront. For HUDs, the diffractive combiner element is manufactured to reflect the precise frequency (about 12 nm wide) emitted by the CRT, yet pass all other light frequencies. The net result is a very efficient use of the available CRT light and very good transmissivity of the rest of the spectrum which is coming from the outside world. When viewing the outside world through the HUD combiner, it reflects (removes) green and passes the rest which results in a light rose or pink cast to the image.

The F-16 Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) wide-angle HUD (see Figure 3) uses a holographically manufactured diffractive combiner. This HUD does not project a holographic image, it merely uses a combiner element that has a holographically produced diffraction grating that coincides with the 543 nm peak wavelength of the CRT's P-43 phosphor. This HUD is a pupil-forming system with a 28 degree field of view.

HMDs

Helmet-mounted displays are virtual image optical systems that are in many ways similar to HUDs, but with certain distinguishing features. HMDs often utilize miniaturized CRTs or light-emitting diodes as image sources. CRT size reduction has continued from around one inch diameter tubes to today's 0.25 inch, high resolution, high luminance tubes. Referring to Figure 4, the image is typically folded with a front-surface mirror, then collimated with a lens and reflected by the combiner into the observer's eye. If the design uses a relay lens, the HMD will be of the pupil-forming type. HMDs are most often pupil-forming systems. All of these electro-optical components are miniaturized and mounted in some fashion to the pilot's helmet. The combiner is either beneath the visor or an integral part of the visor. The displayed imagery can be a simple reticle, HUD-like symbolic flight information, or complex imagery from a sensor, such as from a forward-looking infrared system. If the display incorporates a reticle to aim a weapons system or helmet-mounted sight (HMS), it must include remote sensing devices that determine the helmet's line of sight. Remote sensing systems can use infrared or magnetic methods to determine helmet orientation. The HMS controls the sensor movement and the HMD displays what the sensor is aimed at, thereby forming a closed-loop system.
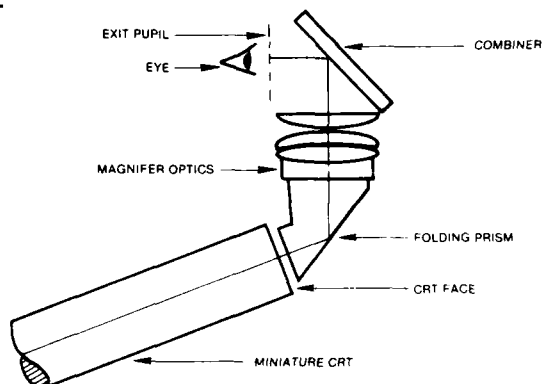
Figure 4. Idealized HMD system.

The basic design and function of CRT, HUD, and HMD systems have now been described in some detail. Each has a large number of parameters to be considered in its design. The realized performance of a particular display system is the result of the interaction of these numerous qualities, some of which have a more pronounced effect than others. The next section describes the major display system parameters and methods of their quantification. The last section will then show how some of these measurements can be combined with human visual system characteristics in an attempt to model and predict visual performance when using a display system of known qualities.

PHOTOMETRY

The measurement of several important display parameters involves the quantification of light energy. The basic tool for light measurement, when human vision is involved, is the photometer. This device measures light energy that is weighted by the photopic curve (see Figure 5), which represents the human eye's varying sensitivity to light as a function of wavelength, or color. Note that the eye is most sensitive to green and least sensitive to blue and red. The photometer measures luminance using foot-Lamberts (or NITS) as units. If a red and green light are adjusted to equal luminance, they would appear (near) equal in subjective brightness. If they were adjusted to have equal radiant intensity (watts/steradian), the green light would appear much brighter than the red light.
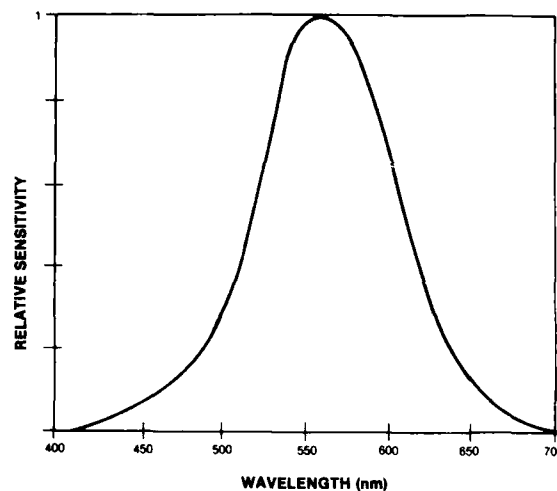
Figure 5. The photopic curve.

A diagram of a photometer is shown in Figure 6. Light enters the objective lens and is reflected by mirrors to the eyepiece to enable the observer to aim and focus the instrument. The first mirror has different sized holes (or apertures) that are seen as black circles (or slits) by the observer. The correctly sized aperture is selected for the object to be measured by rotating the mirror. The light to be measured passes through the aperture and covers the entire surface of the photomultiplier tube (PMT). Filters are used to weight the measurement so the PMT responds to light according to the photopic curve. The output voltage of the PMT is then converted and displayed. Since the photometer integrates all of the energy across the aperture area, the object to be measured must completely fill that area, or errors would occur. Luminance measurements of CRTs are unique in that the horizontal raster structure may affect the accuracy of the readings. A large circular aperture could be used to integrate energy from multiple lines, but it does not lend itself to scanning vertically oriented square-wave test patterns. A vertical slit aperture, oriented perpendicular to the raster structure, is best suited to measure CRTs. The photometer can be mounted on vertical and horizontal, motor-driven translational slides to aid the scanning of test patterns.
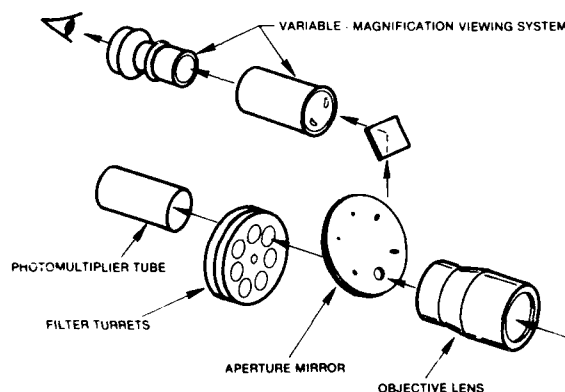
Figure 6. Variable-aperture photometer.

CRT PARAMETERS

CRT display characteristics can be categorized into geometric, electronic, and photometric entities. Table 1 lists these parameters (Task, 1979). For the purposes of this discussion, only the modulation transfer function (MTF) will be discussed in detail since it embodies many of the other parameters and is used extensively in the formulation of display image quality metrics.

Table 1. CRT display system parameters.

GEOMETRIC	ELECTRONIC	PHOTOMETRIC
Viewing Distance	Bandwidth	Luminance
Display Size	Dynamic Range	Gray Shades
Aspect Ratio	Signal/Noise	Contrast Ratio
Number of Scan Lines	Frame Rate	Halation
Interlace	Field Rate	Ambient Illumination
Scan Line Spacing		Color
Linearity		Resolution
		Spot Size
		MTF
		Luminance Uniformity
		Gamma

In the past several years, the MTF measure of display quality has received considerable attention. The MTF has been used as an indicator of the quality of film and photographic systems, of optical systems and lenses, and more recently of CRT displays. Theoretically, the MTF of a system indicates the percent modulation the system will pass as a function of spatial frequency for a sine-wave signal.

Since any signal (or picture) can theoretically be resolved into a set of component sine waves, it is possible to predict how the signal (picture) will appear after passing through a system with a known MTF. Therefore, if the MTF of a system is known, the signal (picture) degradation caused by that system can be calculated. However, the system must be linear and continuous before MTF techniques can be applied. Unfortunately, CRT displays are nonlinear devices, so care must be taken when applying MTF analysis to them. There are several ways to obtain the MTF of a CRT display. Most of these methods require mathematical manipulation of empirically measured signals and assume linearity of the CRT display. Mathematically, the MTF of a system is defined as the Fourier transform of the point spread function of the system. The point spread function is the resultant output signal from a system for a point or very narrow impulse input signal. Rigorous treatment requires the input to be of zero width and infinite height; practically, the spike needs to be much narrower than the spread caused by the system being tested. For CRT displays, the point spread function is typically obtained by measuring the spot profile produced on the face of the CRT by the scanning electron beam. This spread function is then used to obtain the MTF by applying the Fourier transform theory. Another approach is to assume the CRT spot profile is a Gaussian distribution (Equation 2) and calculate the MTF (Equation 3). A Gaussian distribution is used because the Fourier transform of a Gaussian distribution is easily obtained in analytic form, thus eliminating the necessity of using numerical Fourier transform techniques and a computer. CRT spot profiles are typically near Gaussian. Equation 3 is the normalized Fourier transform of Equation 2. Figure 7 shows a typical MTF generated by this method.

$$L(x) = Ke^{-1/2(x/\sigma)^2} \tag{2}$$

where:

L = luminance distribution
K = constant
x = spatial parameter (length)
σ = standard deviation of the Gaussian distribution

Taking the normalized Fourier transform of Equation 2 yields the MTF.

$$MTF(f) = e^{-2(\pi\sigma f)^2} \tag{3}$$

where:

f = spatial frequency
σ = standard deviation of the Gaussian distribution
$MTF(f)$ = fractional modulation
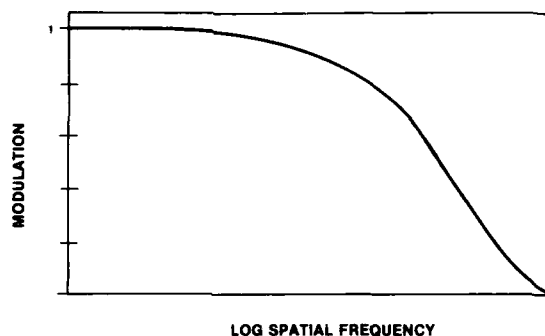
LOG SPATIAL FREQUENCY

Figure 7.   Typical MTF obtained from calculations based on assuming a
Gaussian distribution spot profile as a point spread function.

Other methods of obtaining the MTF of a CRT display require Fourier analysis of square-wave, line, or edge patterns.   In each case, the MTF must subsequently be calculated, assuming linearity of the display.

The direct method of obtaining the display MTF is to measure the modulation transfer of the display for sine-wave signals of various frequencies.   The problem with applying this approach to CRT displays is that the input signal is electronic (measured in volts) and the output signal is photometric (measured in ft-L).   Thus, the output to input ratio (percent of modulation transfer) is not clearly defined.   Typically, this problem is circumvented by using a normalization procedure, the results of which can be misleading.

The sine-wave response (SWR) measurement technique (Task and Verona, 1976) was devised to avoid the problems inherent in calculating the MTF by using the various methods described.   The SWR relates the maximum modulation contrast capability of the display to spatial frequency, measured directly, frequency by frequency.   This differs from the MTF in two important respects: (1) it does not assume linearity of the CRT display, and (2) it is not a normalized function.

HUD PARAMETERS

The next section describes the optical quality measurement procedures that were adopted to evaluate the LANTIRN HUD (Task, 1983).   The objective of these measurements was to determine how suitable the HUD optics were for matching human visual require-ments.   The measurements were directed to the optical components and did not include the cathode-ray tube (CRT) and symbology generation quality.

Measurements fell into two broad categories, those that characterized visual quality viewing through the combiner (effect on target acquisition) and those that concentrated on the visual characteristics associated with viewing the symbology. Table 2 shows the variables that were measured.

Table 2.   Image quality measurement parameters.

COMBINER EFFECTS	SYMBOLOGY EFFECTS
MTF	Collimation
Optical Power	Image to Ghost Ratio
Spectral Transmissivity	Exit Pupil
Photometric Transmissivity	Reflections
Reflections	

Measurement procedures for each of these parameters will be described with its relationship to and effect on vision.

The MTF of an optical element (combiner) describes the transfer of contrast (or modulation) through the element.   It is usually one of the most important quality measures for any imaging system since it can precisely predict the loss in image quality due to the imaging system and, therefore, accurately predict the loss in visual performance.   There are several ways to measure the MTF of an imaging system.   The most straightforward way is to input to the system high contrast targets that vary sinusoidally in luminance in one dimension.   The contrast at the output end is then measured using a photometer and the ratio of contrast out to contrast in is calculated. This is the modulation transfer factor for that particular sine-wave spatial frequency target.   This process is then repeated for other spatial frequencies resulting in a curve of modulation transfer factor versus spatial frequency, which is the MTF. Spatial frequency refers to the number of sine-wave cycles per unit length or per unit

angle, depending on the application. Since we are interested in the relationship to human vision, the units of cycles per degree are most appropriate for measuring the HUD combiner MTF. Modulation contrast is defined by Equation 4.

$$M_C = \frac{L_{MAX} - L_{MIN}}{L_{MAX} + L_{MIN}}$$ (4)

where:

M_C = modulation contrast

L_{MAX} = peak luminance level

L_{MIN} = minimum luminance level

For measuring optical systems, it is not easy to produce high contrast, high quality sine-wave targets to directly measure the MTF. An alternate method that makes use of linear system analysis is equally effective and uses simple square-wave targets. This is the procedure that was used to evaluate the HUDs. A square-wave pattern can be mathematically represented by a series of sine waves as demonstrated by Fourier analysis. By inverting the series, it has been shown that a sine-wave response (MTF) can be calculated from the square-wave transfer function using Equation 5.

$$MTF(f) = \pi/4 \left\{ C(f) + C(3f)/3 - C(5f)/5 + C(7f)/7 \ldots \right\}$$ (5)

where:

MTF = sine wave response
f = spatial frequency
C(f) = square wave contrast transfer at frequency (f)

Normally, the MTF of a planar section of glass (such as a HUD combiner) should have an excellent MTF, i.e., no loss in contrast across the full spatial frequency sensitivity region of the human eye (0 to 60 cycles per degree). However, if there are reflections or light scattering effects, this will result in a lower MTF uniformly across all spatial frequencies. It is, therefore, very important to measure the MTF of the HUD under the conditions in which it will be used to include the degrading effects of reflections and light scatter. An alternative is to measure the HUD combiner in a dark room to eliminate these effects from the measurement and mathematically include them later as explicit reflection coefficients. This latter approach may be preferable, since it would then be possible to accurately predict the MTF (and, therefore, contrast and visual performance) for any ambient lighting condition.

A photometer with a narrow, vertical slit aperture was used to scan a square-wave target pattern with the HUD interposed and with the HUD removed. The MTF of each of these square-wave responses was then calculated. The MTF with the HUD in place (MTF of HUD and photometer) was then divided by the MTF without the HUD (MTF of photometer only) to obtain the MTF of the HUD by itself. This procedure was carried out in a dark room which resulted in an essentially flat MTF (no spatial frequency dependent losses) over the full range of spatial frequencies of the human visual system.

For the most accurate results, the aperture of the objective lens of the photometer should be no larger than the pupil diameter of the human eye under the luminance conditions of interest (2-3 mm diameter for daylight; 7-8 mm diameter for night). If a larger diameter is used, the MTF obtained does not correspond to what the observer will see, but will, in general, be somewhat poorer.

If the HUD combiner is indeed a flat plate, then it should have no optical power (no lens effects). However, if the combiner is a curved section, or is formed from glass sections cemented together, then it may contain some optical power. The effect of this optical power may combine with the HUD divergence/convergence errors and the windscreen lens effects to increase or decrease the possibility of diplopia (double imaging). The optical power was measured by mapping the angular deviation of light rays passing through the combiner from each eye position as a function of azimuth and elevation. The difference in angular deviation from the two eye positions was then calculated. The angular deviation was measured using an F-16 windscreen movement table and an optical angular deviation measurement device (Task, Genco, Smith, and Dabbs, 1983).

For most HUDs, the spectral transmissivity measurement is not really required, because the combiner coating is usually neutral with respect to wavelength. In other words, it passes a percentage of the light incident on it independent of wavelength. However, if the HUD combiner uses holographic optical elements (HOEs), such as the LANTIRN HUD, or if it has a dichroic or trichroic coating, the transmission of the combiner needs to be measured for each wavelength, resulting in a spectral transmissivity curve. A spectral scanning radiometer and a light box were used to make this measurement. The procedure was to make a spectral scan on the light box by itself,

then make a spectral scan of the light box through the combiner of the HUD. The second scan was then divided (wavelength by wavelength) by the first scan to yield the spectral transmissivity of the HUD. This process was done in a dark room to insure that reflections did not contaminate the readings. It is important to be careful of the size of the aperture of the radiometer to insure that all the light entering the radiometer has gone through the area of interest on the combiner. In the case of the LANTIRN HUD, the upper, "eyebrow" section was fairly narrow (see Figure 3), making it somewhat more difficult to measure its spectral transmissivity. Figures 8 and 9 show the spectral transmissivity through the eyebrow and central area, respectively, of a LANTIRN HUD.

Figure 8. Spectral transmissivity through the eyebrow portion of the LANTIRN HUD.
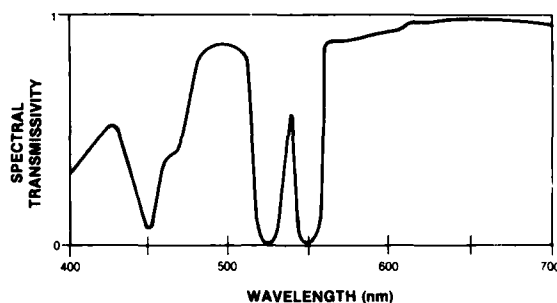
Figure 9. Spectral transmissivity through the central portion of the LANTIRN HUD.
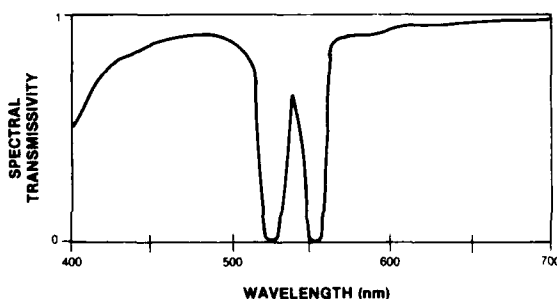
The spectral transmissivity curve can be used to calculate the photometric transmissivity through the HUD of various objects of differing spectral distributions (colors). If the spectral transmissivity of the combiner is flat across all visible wavelengths, then the photometric transmissivity will be the same independent of the color of the object viewed. However, if the spectral transmissivity is not flat (as in the case of the LANTIRN HUD), then the photometric transmissivity is object dependent. As previously stated, the human visual system is not equally sensitive to all wavelengths of light. The eye's spectral sensitivity for daylight conditions is referred to as the photopic response curve (Figure 5), which is the basis for photometry. The photopic response curve peaks at about 555 nanometers and ranges from about 400 nm to 700 nm. The photopic transmissivity of the HUD depends on its spectral transmissivity, the photopic curve, and the spectral distribution of the object viewed. The photopic transmissivity in equation form is shown as Equation (6).

$$T = \frac{\int_{400}^{700} V(\lambda)\ S(\lambda)\ T(\lambda)\ d\lambda}{\int_{400}^{700} V(\lambda)\ S(\lambda)\ d\lambda} \qquad\qquad (6)$$

where:

T = photopic transmissivity
V(λ) = photopic sensitivity curve
S(λ) = spectral distribution of the object
T(λ) = spectral transmissivity of the HUD

The spectral distributions of several objects were measured and the photometric transmissivity was calculated for each using data obtained on a LANTIRN HUD (production versions were expected to be better than the prototype), as shown in Table 3. These values were calculated assuming unpolarized light coming from each of the objects. In the case of blue sky, this is probably not a good assumption. Using the light box and a polarizer filter, the effect of polarizaton of light on the transmissivity was measured and is shown in Table 4.

Table 3. Photometric transmission through a LANTIRN HUD for various typically encountered objects.

OBJECT	EYEBROW	CENTER
Light Box (Measured)	54.8%	65.1%
Light Box (Calculated)	54.9%	65.1%
Blue Sky	46.0%	57.8%
Green Grass	46.8%	57.2%
Hazy Horizon	49.1%	59.9%
Distant Trees	47.5%	58.4%

Table 4. Effect of polarization on HUD transmissivity.

POLARIZATION	EYEBROW	CENTER
Vertical	61.0%	70.2%
Horizontal	55.9%	67.8%
None	58.4%	68.7%

The windscreen also has a polarization effect on transmissivity that combines and enhances the effect due to the HUD. The net result is an overall transmissivity that may vary by 10% to 15%, depending on the aircraft's orientation with respect to partially polarized skylight.

It is difficult to provide a specific measurement procedure for reflections because of the tremendous variations in the types of reflections that occur due to the different optical designs. In general, reflections are unwanted sources of light that are superimposed on the combiner causing a loss of contrast of both the outside world scene and the HUD symbology. In addition, the reflections may form real or v tual images of interior or exterior objects that act as a distraction to the observer. These reflections should be characterized as to the location of the image, the image source, and the relative luminance of the image with respect to the source (reflection coefficient). If the reflection has a different spectral distribution than the source, then it is necessary to measure the spectral reflection coefficient to properly describe the reflection. It is not possible to cover all these variations in the limited space available in this paper, so only one type will be considered to demonstrate the measurement approach to reflections.

In the case of the LANTIRN HUD, a reflection occurs from the flat HOE closest to the observer that reflects objects in the knee area of the pilot in the cockpit. This reflection is in a relatively narrow spectral band in the green wavelengths (543 nm). The reflection produces a virtual image of the knee area several inches forward of the combiner. A diffuse white light source (2700 Kelvin) was used as a "target" in the knee area. The luminance of the diffuse light source and its green reflection in the HUD combiner were both measured using a photometer. The reflection luminance was divided by the source luminance to obtain a reflection coefficient (to fully characterize this reflection, a spectral reflection coefficient should have been measured). This reflection coefficient varied somewhat across the face of the combiner, but was about 8-10%. This information, coupled with the MTF measurement, can be used to accurately predict the contrast loss viewing through the HUD for any given ambient lighting and target luminance condition. Equation 7 shows how this is done mathematically.

$$M_C = \frac{L_B T_W T_C - L_T T_W T_C}{L_B T_W T_C + L_T T_W T_C + 2RL} \qquad (7)$$

where:

M_C = Modulation contrast

L_B = Background luminance

L_T = Target luminance

L = Reflection source luminance

T_W = Windscreen transmittance

T_C = Combiner transmittance

R = Reflection coefficient of combiner

If R=0, there are no reflections and the contrast depends only on the target and background luminance. Note, however, that the resulting target contrast with reflections depends explicitly on the target and background luminances. This means that two targets with identical contrasts with their backgrounds will undergo different amounts of contrast loss for the same reflection situation if their luminances are different. Similar mathematical relationships exist for multiple reflections, chromatically selective reflections, etc. It should be noted that these contrast losses also occur for the HUD symbology, although a slightly different mathematical relationship applies.

Optical systems, such as HUDs, are typically composed of several optical elements, usually resulting in many air-glass interfaces. Uncoated glass will typically reflect about 4% of incident light at an air-glass interface. This effect results in unwanted real or virtual images of the object to be imaged (CRT symbology, in the case of the HUD). To minimize this effect, surfaces are normally coated with an antireflection coating. This substantially reduces the effect, but does not eliminate it, so there are usually ghost images that may be visible and distracting to the observer. There are several ghost images visible; two near the primary image and one to the right of the primary. A standard measurement (and specification) is the image to ghost ratio. This is determined by measuring the luminance of the primary image and then the luminance of the ghost images. The ratio of the primary image luminance to the ghost image luminance is the image to ghost ratio. In the case of the particular LANTIRN HUD ghost image, it was a very acceptable 300:1 ratio.

The original concept of a HUD was to place an aiming reticle and critical flight/weapon information in such a position that the pilot could keep his head out of the cockpit. The HUD symbology was collimated so that he did not have to refocus his eyes when switching from looking at the target and viewing the symbology, so the aiming reticle would appear at the same optical distance as the target. This eliminated parallax errors between the target and the reticle. Since outside targets are always far away, the HUD image was collimated or set for optical infinity. As with any physical parameter, there must be some tolerance allowed about the ideal value based on requirements; in this case, on the requirements of the human visual system and desired weapon system aiming accuracy. Since the HUD image and outside world target are viewed binocularly, there are two distinct concerns associated with the HUD image optical distance. First, can the eye lens focus on the imagery and the target at the same time? Second, will the two eyes fuse their separate views into one image or two? The first concern is usually no problem. However, the second concern, which also relates directly to parallax error (and therefore weapon system accuracy), is a major concern.

The best way to test for collimation is to measure the binocular convergence or divergence (vergence) of the HUD. This occasionally gets confusing because a HUD which has a diverging image causes the eyes to converge in order to fuse the image and a converging HUD image causes the eyes to diverge. It is necessary to have a measurement procedure for vergence for both the HUD image and of outside objects as they pass through the windscreen.

To measure the HUD image vergence, a laboratory developed binocular measurement device was used. This device (Task, 1981) was originally developed to measure the alignment of binocular display systems, such as two-eyed helmet-mounted displays, and was later generalized to HUDs and windscreens. Two objective lenses in front simulate the two eyes of an observer. Through a series of beamsplitters and prisms, the two images produced by these lenses are combined to form a single image viewed through an eyepiece. A color filter is placed in one side so that the two images can be identified. The two objective lenses are put in the design eye position of the HUD and the HUD symbology is viewed through the device. A moveable mirror is adjusted until the two images of the HUD symbology are fused into one. In this position, the device's "eyes" are converged (or diverged) to intersect at the plane of the HUD symbology. The device is then removed from the HUD and is moved toward or away from some convenient object until the two images are again superimposed (the mirror is not adjusted during this process). The angle of convergence is then calculated from the distance between the two lenses and the distance to the physical object. For converging HUDs, a slightly different procedure must be used. This general procedure has now been changed by introducing a reticle into the measurement device so that the convergence/divergence can now be read directly from the reticle. It should be noted that vergence tolerances depend on an individual's interpupillary distance (IPD). Those with eyes set wider apart will be more susceptible than those with a smaller IPD.

HMD PARAMETERS

There are many design parameters associated with HMDs. Careful consideration must be made in specifying these to insure the operational utility of the HMD for the particular application. Desired values of many of the parameters change, depending on the applicaton for which the HMD will be used. Table 5 provides a list of the design parameters (Task, Kocian, and Brindle, 1980), some of which will be discussed in this section.

Table 5. HMD design parameters.

Size/Weight/Center of Gravity	Image to Ghost Ratio
Monocular vs Binocular	Color/Color Contrast
Exit Pupil	MTF
Eye Relief	Image Source Quality
Apparent Field of View	Roll Stabilization Compatibility
Collimation	Combiner Reflectivity/Transmissivity
Distortion	System Transmission Efficiency
	Safety

By far the most common HMD has been monocular. The advantages of a monocular HMD are smaller size, less weight, easier alignment and lower cost. The binocular HMD does, however, provide an image to each eye. This prevents any possibilty of binocular rivalry occurring if the two images are identical or are a stereo pair. There has been concern with the potential for binocular rivalry in monocular HMDs for many years (Birt and Task, 1973; Hershberger and Guerin, 1975; Laycock, 1976). Many parameters (luminance, contrast, etc.) have been shown to have an effect on the subjective incidence of binocular rivalry (Hershberger and Guerin, 1975). In general, the more disparate the images to each eye, the greater the possibility for rivalry to be a problem. HMDs that present symbology only (no imagery) at a luminance level compatible with the external scene luminance show little or no potential to induce rivalry. In the application where the HMD displays imagery from a sensor, the potential for rivalry increases. The severity of this effect has not been determined. Individuals involved in HMD activities vary in their opinions from indicating that there is no rivalry problem to insisting that the problem is severe. However, most agree that the susceptibility to binocular rivalry depends heavily on the individual and the specific display conditions.

Most HMD applications require that the HMD image be collimated. This is important for target acquisiton. If the image is not collimated, then the image (e.g., a sight reticle) would move with respect to the target as the eye shifted laterally in the exit pupil. For other than direct target acquisition applications, it may be desirable not to have the image collimated. For example, if the HMD is used for viewing sensor imagery, it may be desirable to fix the image location in the same plane as the instrument panel, thus permitting the wearer to switch between the HMD image and the panel instruments without changing his eye accommodation distance. This may also decrease the potential for binocular rivalry for viewing outside the aircraft as the observer would look through the HMD scene when observing the exterior scene, although some studies have not shown this effect for subjective rivalry assessment.

Distortion occurs as a result of nonlinear transformations from the image source through the optical system. Typically, distortion appears as barrel or pincushion-like in rotationally symmetric optical systems (see Figure 10). However, HMDs using a parabolic visor as an optical element in the HMD optical chain suffer from a parabolic distortion (see Figure 11).

Figure 10. Typical distortion in rotationally symmetric optical systems: (A) barrel distortion, (B) pincushion distortion.
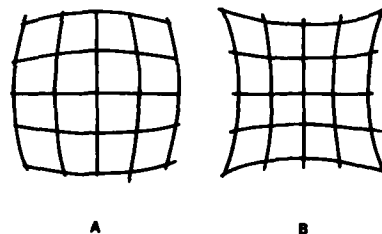
Figure 11. Parabolic distortion increases by the use of the parabolic visor.
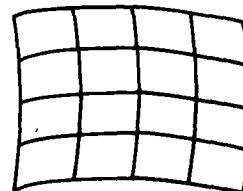
Barrel and pincushion distortion may or may not be severe enough to require special correction, but parabolic distortion does. In general, the distortion and other aberrations are reduced as the number of optical elements is increased; however, this causes an undesirable increase in weight. A reasonable compromise between number of elements (weight) and optical aberrations must be achieved. Also, depending on the technology used, a particular optical design may employ either $F(\theta)$ or $Tan(\theta)$ mapping. For $F(\theta)$ mapping, the image field angle is proportional to the image source chordal

height, whereas, in Tan(θ) mapping, the tangent of the field angle is proportional to the chordal height of the image source. The characteristics of the image source must be matched to the type of optical mapping. Field curvature and astigmatism may also present problems, especially as the field of view for a particular design is increased. Field curvature can easily be corrected by attaching an appropriately shaped fiber optic faceplate to the image source. Distortion and mapping problems can be corrected by the addition of compensation electronics within the CRT deflection amplifier signal path. An often used approach to this problem is to first generate a mathematical representation or least squares fit of the distortion which must be compensated for and then determine the number of significant coefficients for a given percent decrease in distortion at the observer's eye. The selection of these coefficients must also be balanced against what represents a practical requirement for the electronics hardware. Critical for the hardware is the small signal bandwidth requirements that the compensation electronics must meet based upon either the highest line rate at which the system must operate in a raster mode or the step response/settling time characteristics for a stroke-written mode of operation. Due to the methods which most analog circuits use to generate terms with arbitrary exponents, the inclusion of a second order term will approximately double, and the addition of a third order term will nearly triple, the bandwidth requirements for the compensation circuits. Depending upon signal bandwidth requirements, the inclusion of only a few higher order compensation terms will, with current technology, severely strain state of the art performance for the analog multipliers that are generally used in such applications, as well as the signal-to-noise performance of supporting electronics. The above considerations are an illustration of the necessity for considering all components of the helmet-mounted display system early in the design development process so that appropriate trade-offs can be made.

IMAGE QUALITY METRICS

Any calculated measure of image quality must include characteristics of both the human visual system and the display imaging system. There are many measures of each of these but the ones most often employed in developing image quality metrics or figures of merit are the MTF for the display system and the contrast threshold function (CTF) for the visual system. The following sections describe the MTF and the CTF and ways that they have been combined to form image quality metrics.

As previously described, the MTF is formally defined as the real part (or modulus) of the normalized Fourier transform of the system point spread function of the system (Gaskill, 1978). In addition, it is only applicable to linear, continuous, and homogeneous systems. In practice, these restrictions are ignored and the concept of MTF is applied in a much simpler fashion. The MTF of a complete display system (input sensor, video electronics and display monitor) can be measured directly by imaging high contrast sine-wave test patterns through the system. The ratio of the output contrast to the input contrast is the modulation transfer factor for the spatial frequency of the test pattern. The collection of modulation transfer factors as a function of spatial frequency is the MTF. Another way of thinking of the MTF is that it describes the maximum amount of contrast possible as a function of spatial frequency (Task and Verona, 1976). An example of a typical display system MTF is depicted by the upper curve in Figure 12. Note also that the spatial frequency may be presented in several types of units. For example, cycles per inch, cycles per millimeter or cycles per display width describe the spatial frequency in linear units. More appropriate for human observer related situations is to describe the spatial frequency in angular terms such as cycles per degree (cpd) or cycles per milliradian.
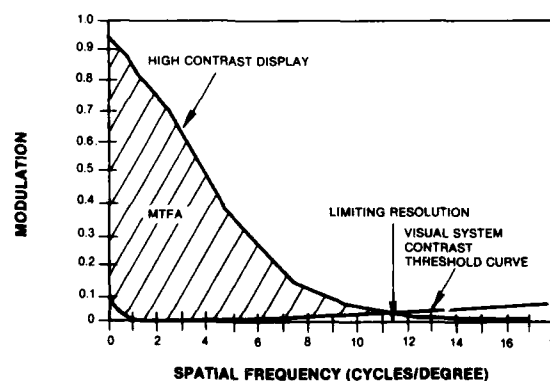
Figure 12. Pictorial representation of MTF, MTFA, and limiting resolution.

Human visual capability can be measured with a related technique using sine-wave test patterns. The procedure is to have the observer view a sine-wave test pattern that has a contrast so low that he/she cannot detect it. The contrast is then increased until the individual can detect the pattern. The contrast at which detection occurs is then recorded and the procedure is repeated at other spatial frequencies.

The resulting graph of detection contrast versus spatial frequency (Cornsweet, 1970) is called the contrast threshold function (CTF). The reciprocal of the contrast threshold function is often used to describe visual capability; this is called the contrast sensitivity function (CSF). It should be noted that the CSF is not the same as the MTF of the human visual system (Snyder, 1985). There are many variations in procedures for measuring the human visual contrast threshold function which give different results, but the basic goal is the same: determine the visual threshold contrast of a sine-wave test pattern.

The display system MTF and the human visual system CTF can be combined to form a class of image quality metrics (Borough, et al, 1967; Snyder 1974; Task, 1979). Figure 12 shows both the display system MTF and the visual system CTF graphed together. The area between the two curves has been designated the modulation transfer function area, or MTFA (Borough, et al, 1967 and Snyder, 1974). The MTFA provides a value that could be considered to be the information bandpass of the display/observer system. Any contrast value outside of this area either cannot be produced by the display system (above the MTF) or cannot be detected by the observer (below the CTF). Furthermore, the intersection of these two curves indicates the highest spatial frequency the display can produce that the observer can detect; also known as the limiting resolution of the system.

It has been proposed that the MTFA might be a reasonable indicator of image quality since it does combine characteristics of both human vision and display capability. Many variations of this fundamental concept have been proposed and tested (Task, 1979). Table 6 provides a short list of some of the variations that have been proposed.

The objective of each of these measures of image quality is to manipulate the contrast and spatial frequency axes of the MTF and CTF such that the resulting area linearly relates to human visual performance.

Table 6. Image quality metrics.

METRIC	DESCRIPTION
Modulation Transfer Function Area (MTFA)	Area between the display system MTF and the observer contrast threshold function.
Log MTFA	Logarithm of the MTFA
Limiting Resolution	Intersection of display MTF with observer CTF
Log Bandlimited MTFA	Logarithm of the area between the display MTF and the observer contrast discrimination threshold above two cycles/degree.*
Integrated Contrast Sensitivity (ICS) (van Meeteren, 1973)	The integral of the ratio of the display MTF and observer CTF

* Note: The contrast discrimination threshold function describes the amount of contrast an observer requires using a square-wave test pattern to just determine that it is a square-wave pattern and not a sine-wave pattern (Campbell and Robson, 1968).

TARGET RECOGNITION AND DETECTION STUDY I

To test the predictive power of several image quality metrics, a video based target recognition and detection study was conducted (Task, 1979). The objective of the study was to investigate the correlation between the various image quality metrics and observer performance for both a target recognition task and a target detection task.

Summary of Study: A total of 72 subjects participated; all were checked for 20/20 Snellen acuity. Ages for the 36 male and 36 female subjects ranged from 18 to 30 years. Subjects were seated in front of a video monitor at a distance of 28 inches. For the target recognition task, a target would appear in the center of the screen too small to be recognized and then would slowly increase in size until the subject could determine which of 6 targets was present. The targets were randomly presented in each of 4 orientations for a total of 24 presentations per subject. For the target detection task, an aerial terrain view was presented simulating the view from a low flying aircraft. The subject was prebriefed on the targets. Targets consisted of a set of large petroleum storage tanks. Two simulated altitudes were used: 1000 feet and 2000 feet.

A total of nine display system MTF conditions were included in the study. These included all combinations of three bandwidths (6, 1, 0.4 MHz) and three maximum contrast ratio settings (50:1, 50:5, 50:15). Eight subjects participated in each of the nine MTF conditions.

For the target recognition task, the angular subtense of the target at recognition was used as the dependent performance variable. Slant range (in simulated feet) to target at detection was the dependent variable selected for the target detection task.

Results: For the target recognition task, the average angular subtense of the target at recognition was calculated for each subject. This provided eight performance measures (one from each subject) for each of the nine display system conditions. The overall average performance for each display condition was the average performance of the eight subjects. This resulted in nine performance measures (one for each display condition) that could be correlated with calculated image quality metrics to determine which metrics best related to performance. Table 7 is a summary of these correlations.

The target detection task was divided into two parts by simulated altitude. The average slant range to target at detection for each condition was calculated as the performance measure and correlated with the image quality metrics as in the target recognition study. Table 7 also shows these results.

As should be evident from Table 7, all of the image quality metrics investigated correlated to some degree with human observer performance for both the target recognition task and the target detection task. The logarithm of the bandlimited MTFA (BLMTFA) correlates best overall. This would imply that the midrange spatial frequencies (2 - 8 cpd) are most important for the type of tasks investigated since the log BLMTFA emphasized this portion of the area more so than the other metrics.

Table 7. Correlations between image quality metrics and performance - Study I.

METRIC	RECOGNITION	DETECTION (1000ft)	DETECTION (?000ft)
MTFA	-0.81	0.83	0.72
Log MTFA	-0.88	0.87	0.78
Limiting Res	-0.76	0.78	0.70
Log BLMTFA	-0.95	0.93	0.88
ICS	-0.82	0.84	0.72

Note: A total of 19 image quality metrics were tested in this study; see Task, 1979 for more information.

This study used a general contrast threshold function (Campbell and Robson, 1968) to calculate all of the image quality metrics for the nine display conditions instead of measuring the CTF for each subject. This was done as a matter of convenience. Thus, the changes in the value of the image quality metrics were due solely to the display system MTF. Almost all of the image quality metrics demonstrated a reasonable correlation with performance (although some were obviously better than others), implying that the use of a general CTF was reasonable. Since the CTF may vary significantly from individual to individual, there have been some claims that these differences are significant (Ginsburg, 1986). The next question is whether or not using each individual's CTF in the calculation of image quality metrics will result in metrics that relate to performance. The following study was designed to investigate this area as a secondary objective.

TARGET RECOGNITION STUDY II

This study was primarily designed to investigate the effects of monochrome displays of different colors on target recognition performance (Pinkus, 1982) with prediction of individual performance differences from vision measurements as a secondary objective. The same imagery and procedure were used as in the previously described target recognition task.

Summary of Study: A total of 12 college aged subjects participated in this study. A total of six display conditions were established: all combinations of three colors (red, green, white) and two contrast ratios (40:1 and 2:1). A total of 5 vehicle targets served as the stimulus set and were presented to each subject in each of four orientations. All subjects participated in all conditions. The Snellen acuity of each subject was measured by an optometrist and the contrast threshold function of each subject for each color was measured by a separate vision research group. The acuity data, CTF data and visual performance data were not exchange between the various research groups until after the data collection was complete. This eliminated any possibility of experimenter effect since each of these sets of data were obtained independently.

All subjects were required to have 20/20 or better vision, corrected or uncorrected (some subjects wore glasses). The presentation order of the stimulus material was randmomized to prevent learning the order of presentation. The video image was set to 7.5 inches high by 10 inches wide at a distance of 28 inches. A standard 525 line rate, 30 hertz frame rate, 2:1 interlace white P-4 phosphor CRT display was used for all presentations. The red and green conditions were simulated using color filters (a neutral density filter was used for the white condition to keep all the luminance conditions equal).

Results: Fortunately, the subjects varied considerably in their CTFs (thresholds differed by as much as a factor of 10 between individuals for some spatial frequencies)

so there was a very good range of CTFs to test the effect on visual performance. The average angular subtense of the target at recognition was calculated for each subject for each of the six display conditions. Since color was found to have no impact on performance, the data were divided into two groups: high contrast and low contrast. For each contrast condition, image quality metrics were calculated for each subject and color. Since the MTF of the display remained constant for each contrast condition, the only factor to change the value of the image quality metric was the CTF of the subject. The image quality metrics for each subject and color combination were then correlated with performance for the high contrast condition, the low contrast condition and then both conditions combined. Table 8 is a summary of these results.

From the correlations in Table 8, it is apparent that the effect of the individual CTF on the image quality metrics did not result in a measure that correlated with performance. The implication is that the difference in CTFs between normal individuals does not have an impact on visual performance for the types of tasks investigated.

Table 8. Correlation between image quality metrics and performance - Study II.

METRIC	LOW CONTRAST	HIGH CONTRAST	BOTH CONDITIONS
MTFA	-0.27	0.01	-0.58
Log MTFA	-0.27	0.00	-0.58
Limiting Res	-0.24	0.01	-0.52
Log BLMTFA	*	*	*
ICS	-0.01	0.26	-0.20

* Note: These values could not be calculated since the discrimination threshold curves for these subjects were not measured.

From the results of the studies presented, there is one apparent and significant conclusion concerning the role of the contrast threshold function (or contrast sensitivity function) in image quality metrics. Namely, a general contrast threshold function may be used to calculate image quality metrics. The effect of individual's CTFs (or CSFs) does not contribute to the prediction of visual performance for subjects with normal vision even though the differences in these CSFs may be as high as a factor of 10 between individuals at various spatial frequencies.

It is difficult to determine which image quality metric is the best since performance may vary considerably depending on the specific task required of the observer. From the studies described, the log bandlimited modulation transfer function area correlated best overall, however, other measures such as the MTFA and log MTFA were not far behind.

This paper has reviewed the basic physical, electrical, and optical characteristics of CRT, HUD, and HMD systems. The measurement techniques such as the MTF, convergence, and collimation were described in detail. The last part presented the results of two studies that investigated various methods to combine CRT display measurements with the human visual system's resolution and detection capabilities.

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FUTURE VISUAL ENVIRONMENT AND CONCERNS

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SUMMARY

Visual displays play an important role in the cockpit, where the information coming from various sensors is presented to the aircrew, after processing by computers. A classification of the displays is done, considering the needs in modern cockpit architecture, where different systems are possible according to the mission envisaged. For daylight operations, HMD/S or FLIR systems are considered, with their advantages but also their shortcomings and limitations. For night operations, NVG, LLLTV or FLIR systems are assessed, and the current problems discussed. The protection of the eyes of the aircrew against intense sources of light, such as laser or nuclear flash, is also considered briefly.

1   INTRODUCTION

The evolution of air combat has progressed in cycles of theory and practice, driven by the development and applications of new technologies. Following the classic dogfights of the Korean war, our new supersonic fighters with radar and air-to-air missiles entered service. The visual combat with the enemy was neglected because it appeared unlikely to occur. This resulted in poor outside visibility, whereas high speed, good longitudinal acceleration, high altitude capability and a long range were the main requirements. The aerodynamic design was dominated by the need for a low profile drag and a low wave drag. Head Down Displays (HDD) were intensively used, for the radar and the weapon systems associated. The Vietnam conflict, however, revealed the limitations of this approach and lead to a relearning of the basic lessons in air combat. Most current fighters, such as the F15 Eagle and the F16 Falcon, are combining the merits of traditional fighters (good visibility, excellent handling qualities and lethal weapons) with supersonic capabilities. The basic improvements in aircraft performance and manoeuvrability are accompanied by a greater sophistication in avionics, armament and cockpit environnement. This last aspect of the problem being considered, the future threats and the future mission requirements are leading to requirements for the cockpit architecture.

If we consider the future threats, it is evident that the Soviet technology has made tremendous strides. By the year 2000, almost their entire force will be made up of advanced, look-down/shoot-down fighters. And the challenge for NATO is to maintain the ability to build in the technology to counter a numerically superior enemy.

As far as future mission is concerned, the aircraft must of course survive the projected defenses. Added to the airborne threats, more sophisticated Surface-to -Air Missiles (SAM) will also be used. It means that an integrated Avionics/Fire Control/Electronic Counter Measures (ECM) systems are essential to help the crew. The amount of data originating from multimode sensors, both passive and active, leads to the use of new electronic circuits (VHSI) in order to achieve the required processing capability within the available space limit. These systems will be optimaly integrated to provide the pilot with the situation awareness he requires. This presentation is made on displays of various types, which have already been considered before.

2   VISUAL DISPLAYS

2.1 Generalities

To day's and more importantly tomorrow's military aircraft and associated displays must be extremely flexible to cope with a wide variety of weapons and weapon delivery options, active and passive countermeasures,

enemy weaponery and complex piloting problems. Need for greater capability
has lead manufacturers to investigate new technologies to replace the
existing limited devices such as Cathode Ray Tubes (CRT), incadescent readout
and electromechanical displays. A comprehensive study of current modern
display has been completed in the previous paper. As a summary of this study,
the FIG.1 is giving some indications of the technology potentials and an
assessment of the present applications in modern cockpit. The list includes
CRT, Vacuum Fluorescent Displays (VFD), Liquid Cristal Displays (LCD), Plasma
Display Panels (PDP), Light Emitting Diodes (LED), Electroluminescent
Displays (EL) and Electrochemical Displays (ECD). Suffice to say that CRT is
and will remain for some time at the forefront of display technology for
applications in military aircraft at the video end of the spectrum where
operations are required over the full ambient range. The newer flat panel
technologies will find their application where the display needs to operate
only over a restricted range of ambient light. But the potential of new
technologies for modern displays in military aircraft is very promising in
the long run.

2.2 Displays classification

The application of electronic display technology in military aircraft
leads to four basic classifications of visualization format. These formats
and their definitions are taken from Ch.4 AGARD-AR-169 (Ref.2). This
classification is as follows:
- VIDEO   the information is presented in a pictorial form with multiple
shades or color.
- VECTOR-GRAPHIC   the information is presented in both alphanumeric and
simple line drawings with typically one or two levels of luminance in
addition to the off state.
- MESSAGE   alhanumeric information is presented at low-data rates with
not more than two levels in addition the off state (ex. caution or warning
indicators)
- DISCRETE   small amounts of alphanumeric or simple graphic informations
are presented (ex. multifunction key legend).
Specific applications of interest use one or more of the display formats.
To deal specifically with visual displays in general, HUD and HMD will be
considered, and not HDD (Head Down Display) or MMD (Mission Management
Display), although these are also vital parts in a modern cockpit.

2.3 Visual displays

The distribution of normal visual acuity shows high resolving power (one
arc min.) within only a very small area in the central part of the visual
field, the foveal region. Acuity drops sharply outside the foveal region, but
persists at low values over a large area, the peripheral region. This is
illustrated in FIG.2. HUD's are precisely adapted for the foveal field of
vision. Their position in the cockpit, on top of the front panel, is
necessitated by the reclined position of the seat. The HUD combining glass is
located between the aircraft windscreen and the glare shield and transmits
the real-world scene directly while reflecting the display image so that the
two superimposed images are viewed simultaneously by the pilot. Because the
reflected image is collimated to infinity, the angular size and position of
symbol cues projected within the Field Of View (FOV) remain constant with
pilot head motion. The HUD is used to project vector-graphic and video
information. The primary functions of the HUD are flight guidance and weapon
aiming. Therefore a high quality optical system is required, so as to
maintain accurate symbol positioning. The HUD is also used to display symbol
cues for other mission modes such as take-off, landing, navigation, terrain
following and ground collision avoidance. Electro-optical sensor display such
as Forward Looking Infrared (FLIR) can also be presented on the HUD. A
total FOV from 20 to 40 degrees is desirable for fixed wing aircraft. For
example, the FOV of the HUD of the F16 C/D is 25 degrees only, although it is
still considered as a wide FOV for a HUD.
Recent advances in holographically formed optical elements enable the
construction of combiner elements which have very high (90%) reflectivity
over a very narrow band of optical wavelengths. This enables a bright display
to be generated while imposing very little attenuation of the outside scene.
In addition to these advantages, the angular selectivity of the holographic
elements enable compact optical units to be constructed with wide FOV. Most
existing military HUD's are monochromatic, but some color cues are becoming
fashionable.
Due to the limited FOV of the HUD, the Helmet Mcunted Display (HMD) has been
proposed. The HMS (Helmet Mounted Sight) is designed to measure the pilot's
line of sight to a target in relation to the airframe and to process the
information for use in direct control of weapon delivery systems and remote
sensors. It follows that the pilot no longer has to point the aircraft in
order to have the aiming cue superimposed to the target, resulting in
considerable win of time. This is particularly important with the
introduction of stand-off weapons in the inventory. The attitude of the
helmet is measured relative to a selected reference frame. The way this

attitude is measured is beyond the scope of this lecture, but it can be
optical, infrared or magnetic. Also the way the image is projected and
collimated by the optics and presented to the eye after reflection will not
be discussed here.The basic problems which arise are: the weight of the
system, the heat dissipation and the flexibility of the pipe from the
equipment of the aircraft to the helmet. These problems will be solved in the
next future and when one bears in mind that the objective of such a design
must be to achieve the specifications with the least weight penalty and with
minimal obstruction to direct vision, some idea of the problem emerges.

2.4 Future Cockpit

The internal geometry of a single seat cockpit designed in accordance with
today's technical requirements and using the present and future electronic
technologies, is more or less represented by the picture in FIG.3 with the
following equipment characteristics:
- HUD as primary flight operation system
- two TV/tabular displays (to the right and left) mounted close to and in
the shadow of the anti glare-shield, for aircraft system and mission
system operation and messages (including warnings)
- a vertical/horizontal display in the middle part
- possibly a reclinable seat
- pedals
- throttle box
- single row left and right hand console

The aim is to make optimum use of man's channel capacity (perception,
information processing and handling activity capabilities) within the cockpit
It follows hat the cockpit design will be mission orientated. Other
requirements, such as "G" resistance, fatigue, outside vision,... have lower
priority. Although technical requirements for the next fighter aircraft
generation do not yet exist, because the relationships among workload, crew
performance and automation are poorly understood, some scenarios, the most
likely in Central Europe, have lead to some practical requirements in the
following fields:
- system and equipment requirements
- information processing requirements
- environnemental condition requirements

The integrated cockpit equipment concept is thus determined by:
- complex data management with a mixture of centralized (main computer)
and decentralized data processing
- use of combined displays and control panels as determined by the
time-budget and by simultaneous information processing capabilities of the
aircrew

In present day cockpits, some integrated equipment is already in use, e.g.
Multi Function Displays (MFD) or Multi Function Keyboards (MFK). This is in
fact the first step towards the integrated cockpit. Greater integration is
needed in complex mission and flight phases, which involve processing a large
amount of information supplied by the individual systems and its integration.
For certain flight phases such as take-off and landing, or terrain following,
it is already possible to introduce automation, which is a step forward in
integration. But for other phases, such as low level penetration beyond the
FEBA (Forward Edge of Battle Area) or target engagement, in A/A (Air-to-Air)
or A/G (Air-to-Ground) automation is difficult to achieve. In fact the
informations should be presented, already processed according to criteria to
be determined as a function of the threat, with the final decision left to
the pilot. In order to present this information, not only the hardware is
necessary, but also the software which could reduce pilot workload and
increase operational effectiveness. The most important improvement for the
reduction of managerial task load is in the area of fusing the sensor data to
give the pilot macro and micro situation awareness at a glance. It is not
enough to tell him what is going on: the system should give him options which
contribute to increase mission effectiveness. In this respect, there is
ongoing R/D (Research and Development) on large area, high resolution,
sunlight readable, touch sensitive, colour cockpit displays for the head-down
macro situation and helmet mounted systems/displays for the micro situation.
System automation and integration is necessary to avoid an inevitable task
saturation. Considering visual systems only, we assess the role of HUD and
HMD.

2.5 Head Up Display

The amount of information available is almost infinite. Multiple sensors
obtain data which is processed by computers before being presented to the
crew. But the space available is limited and the angular field also. If the
target cannot be put in the FOV of the HUD, its position with regard to the
axis of the aircraft is indicated. This method is acceptable for fixed ground
targets, or targets which are moving slowly on the ground, such as vehicles,
but this is of little use for highly manoeuvring targets, such as aircraft or
helicopters. In this case the eyes of the pilot, combined with head

movements, are the only valuable source of information. It is well known that
loosing visual contact with his opponent means very often, if not always, the
loss of the engagement in A/A. This keeping of visual contact can be
facilitated by the use of sophisticated devices such as HMD, in order to get
real time information on the target, such as its slant range, to perform a
successful engagement.

2.6 Helmet Mounted Display (HMD)

The FIG.4 shows pictorially the concept of a HMD. Sensors are supplying data
which is processed in real time by computers. But one of the most important
sensors is the aiborne radar. Even if its total scan volume is large, it
will never cover the entire volume around the aircraft, particularly the rear
of the aircraft. But a man correctly seated, can look out to the rear and
perceive a situation that can be interpreted by his brain and converted into
actions. This action can be helped by a device which gives informations to
the pilot such as HMD. As previously stated, a HMD is a device attached to an
individual's helmet that produces a virtual image display visible to the
wearer of the helmet. The displayed image may be only a simple reticule or a
complex imagery from an imaging sensor such as a Forward-Looking Infra Red
radar (FLIR). Often the HMD is used in conjunction with a Helmet Mounted
Sight (HMS) which is a device that is capable of determining the helmet line
of sight using remote sensing techniques. This combination is called a
Visually Coupled System (VCS). The HMS determine the helmet wearer's line of
sight; the signals produced by the HMS drive the sensor used in the system
such that it points in the same direction as the helmet. The imagery from the
sensor can then be displayed on the HMD. Thus the sensor is coupled to the
helmet line of sight by the HMS. Both systems working together form a closed
loop system.
The design parameters are numerous, as stated in FIG.5 and will be covered
briefly in the following lines:
  - Size/Weight
  supported by the viewer's head, it has to be minimized, and particularly
  in case of low-level high speed flight where vibrations in turbulence are
  important, or in A/A combat at high G's, any weight on the head is a
  problem. Nevertheless this helmet must remain resistant to shocks which
  occur in turbulence but also in case of any impact in flight (bird strike
  for instance is a great problem)
  - Monocular/Binocular
  A binocular HMD weights more than a monocular one, and the most common HMD
  are monocular, due to their smaller size, weight and cost. If two images
  are produced, there is a possibility of rivalry between both eyes.
  - Exit pupil
  It is the extent to which the eye can move laterally with respect to the
  display before the image is no longer visible. In case of vibrations, or
  helmet slippage, the image could be lost, so that it is recommended that
  the exit pupil be as wide as possible.
  - Eye relief
  It is the distance from the eye to the final element of the optical
  system. This distance must be large enough to prevent interference with
  the observer's eyelashes, or sunglasses or simply for safety reasons.
  - Apparent Field Of View (FOV)
  It is the angular subtense of the HMD image as viewed from the observer's
  eye. The HMD FOV depends on the specific application for which the HMD
  will be used, for example these figures are indicative:
        - symbology only   : 5 to 15 degrees
        - target acquisition : 20 degrees or more
        - piloting/navigating : 40 degrees or more
  - Collimation
  The image must appear to be at optical infinity.
  - Distorsion/Aberration
  Distorsion occurs as a result of non linear transformations from the image
  source through the optical system.
  - Image to ghost ratio
  When the combiner glass is not flat, a ghost image appears. This parasitic
  image must be eliminated to the maximum extend possible. Color contrast
  effects improve the visibility of the good image.
  - Image source quality
  Several parameters are associated with image quality on imaging displays.
  This has been discussed elsewere e.g. in Ref.2
  - Roll stabilization compatibility
  When HMD is to be used in airborne applications, it is desirable to
  provide derotation of the displayed image with respect to the horizon
  and/or the aircraft. Thus when the observer rolls his head, the
  appropriate portion of the HMD imagery rolls in the opposite direction to
  maintain stability with the actual horizon. To accomplish such derotation,
  it is necessary to employ a HMS which measures not only head azimuth and
  elevation but roll as well.
  - Combiner reflectivity/transmissivity
  The selection of the combiner coating, which determines the combiner

reflective coefficient, is probably the most critical HMD characteristic to be specified.
- System transmission efficiency
As the image is transferred from the image source to the eye some image apparent luminosity is lost.
- Safety
The HMD for airborne applications must be designed such that it will not hinder the pilot in case of emergency egress. Some quick disconnect system must be provided. Moreover, as the primary purpose of a pilot's helmet is to afford the pilot some head protection, this capability must be preserved as the HMD is incorporated into or added to the helmet.

The list above shows the problems are numerous. Adding the constraints which exist when such a system is designed for airborne applications, you realize how complex it is to produce a HMD. However some manufacturers are producing such systems, particularly for use in combat helicopters where constraints are easier to overcome. We already know that movements of the head resulting from aircraft vibrations can result in decrement in visual performance. But there is little information about the actual levels of head acceleration in flight, where angular head movements should be measured in various flight conditions. HMD typically consists of three sections:
- an image source
- relay optics
- a combiner element
Let us discuss briefly the role of each element.

2.6.1 Relay optics
This system brings the image source to the viewer's eye and its realization depends on various techniques applied by the manufacturer.

2.6.2 Combiner element
The combiner element, which may also be part of the relay optics, combines the HMD image with the external world scene. The optical coating on the combiner is extremely important since it determines the reflection and the transmission characteristics of the combiner, which in turn determine the see through capability and the relative luminosity levels of the HMD image and the external scene.

2.6.3 Image source
The most basic device is the incadescent light bulb. But CRTs are providing so many possibilities, with high quality image, that they are usually the first choice as an image source. Solid state displays are currently promoted as light weight, flexible, high resolution image source for the future. Efforts are made to reach both high resolution and miniaturization.

HMD tend to divide themselves naturally into two classes, those which are used for sighting purposes only (often referred to as HMS) in which the FOV can be kept small, the displayed information simple and the whole assembly relatively light, and those which are used to display video information using a CRT, with larger FOV and having significantly greater mass. Moreover, the design parameters are very different from those of HUDs. It is virtually impossible to design an acceptable HMD which can be seen by both eyes so that all practical designs appear to have been monocular. Anyhow, wide FOV display is much more difficult to design and many alternative arrangements have been tried in an attempt to find a reasonnable compromise between size, weight, FOV, exit pupil and eye relief.

2.7 Night Vision Goggles (NVG)

2.7.1 Introduction

The ability to operate effectively at night has long been a goal of every airforce in the world, for two very good reasons: first without an airthreat the ground based enemy can redeploy at night more easily; and second, the night period occupies a large fraction of day, around 40% in the European Winter. FIG.6 illustrates this. It is not surprising therefore night vision equipment for flying has been with us for many years and has been the object of much time and resources in development.

2.7.2 Generalities

The visual aids fall into two physical categories: the image intensifiers, which amplify reflected residual light in the near infrared (approx. 600 - 900 nm) and the Thermal Imager (TI) which detects the thermal radiation of all bodies (Planck radiation) mainly in the 8000 - 12000 nm atmospheric window for bodies with temperature around 20 degrees Celsius.
The so called Forward Looking Infrared (FLIR) is a thermal imager while

the NVG belongs to the image intensifiers which also includes Low Level Light
TV (LLLTV). The HMS/D has been specially developed to display information and
to measure the Line Of Sight (LOS) of the pilot's head in order to steer a
sensor platform or a weapon system.
All these images are produced by detecting the radiation in the near or far
infrared and transferring it to the visible range (400 - 700 nm) to which the
human is sensitive.
The visible region lies between 400 nm (violet) and 700 nm (red) of the total
electromagnetic radiation spectrum. The human eye is able to detect this small
spectral distribution with the cones and the rods in the retina. Night vision
systems extend our vision beyond the wavelength red (650 nm) into the near and
far IR by making this radiation visible. A good study of the eye performances
and limitations appear in Ref.6.
Unlike NVG used by troops operating on the ground, NVG for airborne
applications need to permit the pilot not only to look around, but also into
the cockpit with the "naked eye".

2.7.3 Night Vision Goggles

The basic purpose of NVG is to extend the possibility of vision towards lower
light levels with high resolution in the near infrared spectrum. Photocathodes
are used for NVG and a comparison between new and older types (GEN II and GEN
III) of tube sensitivities is given in FIG.7. Note that the information is
taken from other IR fr.quencies and also that the sensitivity is much higher
so that they allow flight operations at lower night illumination.

2.7.4 Current problems

Persistent problem areas with NVG receiving continuous attention are indicated
in the following list, which may not be exhaustive:
   - excessive head supported weight
   - difficulty for some pilots in relaxing accomodations when adjusting focus
   - difficulty for some in alignement of optical center with pupillary axis
   - reduced FOV which increases head movements, and thus crew workload and
     susceptibility to vertigo
   - inadequate contrast related to monochromatic visual image
   - cockpit and position lighting compatibility
   - difficulty with map reading
   - lack of user's ability to adequately evaluate NVG for defects (signal to
     noise, image quality, gain) prior to flight
   - integration with other equipments such as mask, goggles, etc..
   - hardening against potential countermeasures
   - protection of equipment and user against high intensity lights
   - possible desorientation of the pilot in case of system failure or
     saturation by an intense illumination
   - difficulty to estimate a distance, and thus to have adequate field depth,
     particularly with monocular NVG
   - inadequate estimation of available electromagnetic radiation and weather
     influences for each given area of flight operations

These problems can be solved independently of each other. The degree to which
they are overcome depends strongly on the mission envisaged, so that some of
them are given higher priority than others.

2.8 Low Level Light TV (LLLTV)

LLLTV belongs to the same category as NVG, because they operate on the same
principle: to amplify and make visible the residual light reflected by an
object in the near IR. The sensor is looking in a certain cone (usually
forward) and the image is then reproduced on a CRT, or on any kind of display.
Further discussion of this kind of system is beyond the scope of this
presentation.

2.9 Forward Looking Infrared (FLIR)

The thermal image is produced by sensors which detect the IR radiation of all
bodies having a temperature greater than absolute zero (-273°C). The amount
of energy emitted depends on both the object's temperature and its surface
condition, or emissivity, and is independent of ambient light. The temperature
resolution is better than 0.2 degrees.
A schematic set up of the thermal imager components: telescope, scanner,
detectors with cooling unit, signal processing unit, display and eye is given
in FIG.8. Thermal imagers mainly operate in the 8000 - 12000 nm window. The
display used can be the HUD of the aircraft and the image is then collimated
and boresighted to the real world so that it appears as an area of scene with
better clarity. The FLIR sensor has a limited FOV, even if the system is
gimballed, and NVG also has some FOV limitations, which can be reduced by head
movement, so that the operation of both together is interesting. NVG are
designed to minimize weight, so their image performance is somewhat limited.

Low dynamic range tends to lose detail in some low or high light areas. With FLIR installed on an aircraft, more space exists for comprehensive facilities for picture control and enhancement. NVG have to view the scene through the canopy and this can attenuate the NVG spectrum and limit their ability in the low light levels, where FLIR can produce an image of good quality. Thus NVG and FLIR do complement each other both in performance and method of use, and it seems that the combination of both is cheaper than a more complex FLIR gimballed system. Trials have been conducted with a FLIR system on an F-16, called LANTIRN. These were reported extremely encouraging and it looks like this system will enter service in 1989. The evaluation reported some benefits, but also some shortcomings as far as the target is concerned, particularly when it is small and difficult to acquire. Improvements in the navigation system are required anyway, particularly when low level flight is required to minimize aircraft exposure to defenses, and some screening of the target occurs due to relief.

An alternative is to use target designation by a laser. The FLIR system can improve the forward visibility, by picking up details which are not visible by NVG: the latter is limited by the horizontal visibility and also by the residual luminosity of details on the ground, which is also dependant of the cloud coverage.

Numerous manufacturers, in the US and in Europe, have developed and produce systems which enable operations at night. These systems were installed initially on helicopters. A system called TADS/PNVS, which is a combination of target sight and night vision sensor, is widely regarded as the required standard of helicopter equipment for Nap-On-the Earth (NOE) combat flying.

3   PROTECTION

3.1   Generalities

Protection of the pilot means almost exclusively protection of his eyes, because any vision impairement could result in job performance failures. On the other hand, eye protection devices may not induce impairement properties. The challenge is thus rather hard. We will only consider protection against intense light sources, laser or nuclear flash.

3.2   Intense Light Source caused by Laser Systems

The eye is particularly vulnerable to collimated visible and near IR laser radiation. The energy collected by an eye is focussed to a small spot on the sensory retina. The doses required to produce ocular effects are condition dependent on wavelength, exposure duration, Pulse Recurrence Frequency (PRF), retinal irradiance diameter, corneal irradiance diameter, retinal exposure site and the refractive and adaptive state of the eye. The Total Intraocular Energy (TIE) which can be calculated even if binoculars are used, is given in FIG.9 for different operating conditions and for a given wavelength (neodymium laser = 532 nm) Curves are similar for other wavelength (other laser systems). The threat is real and the potential exists for ocular injury due to laser radiation emitted by laser rangefinders and designators already on the modern battlefield. High power lasers are available which can damage eyes at 5 Km and optical sensors at about 3 Km range.

The most common methods employed for laser protective eyewear involve concepts of absorptive or reflective filters. In both cases spectral distorsion can be anticipated and there is a degradation of image quality. Distorsions can be minimized by building visors with very narrow band rejection characteristics. Obviously the narrower the band of visible light which is removed, the least distorsion of perception occurs. Accordingly the protection is also limited.

The absorbing materials are broad spectral band absorbers, and in most cases significantly reduce the visible transmittance of the devices. When these are configured to protect against more than one wavelength in or near the visible spectrum, the transmittance is too low to be usable in many flight environements, particularly in low light conditions. In addition, the spectral distorsion produced by the spectrally selective filters reduces the acceptability of the devices.

On the other hand, the efficiency of rejection devices creates multiple problems which make the system complicated and expensive, but problems involved in producing such a device are solvable. It is necessary that a narrow constant wavelength rejection band be provided for a relatively wide angular field, otherwise spectral distorsions across the visual field are too important. Thus a diffractive system has more chances to be accepted by pilots because the reduction in the visual spectrum is much less than with absorptive systems.

Protection against CW laser sources must be considered. Although most of the laser systems, such as range finders or designators, operate in pulsed mode, CW laser can also be used and produce unpleasant effects with very low power. As CW laser operate in the visible region of the spectrum, the bioeffect of interest is the interference with military missions produced by discomfort glare or ceiling glare. During this period, the pilot can be disoriented.

These effects can be anticipated at ranges 5-6 Km and would be particularly inhibiting under night conditions.

3.3 Intense light source produced by Nuclear Flash

During a nuclear explosion a considerable portion of the released energy is emitted in the form of thermal and visible luminescent radiation. Even at great distances from the point of explosion, this radiation may cause either transient blidness or, in case of greater exposure, irreversible retinal burns. Transient blidness is caused by the visible part of the emitted radiation spectrum whereas permanent damage is, in addition, due to the IR spectral range passing through the eye medium.

Eye protection systems are either so-called passive protective filters, with low transmittance, and thus are a continuous obstruction to vision and cannot be used in airborne operations, or active anti-flash protection systems in the form of optical high speed shutters actuated automatically. The exposure limit is generally of 0.5 Jcm^{-2} to prevent permanent ocular damage. Considering the most probable distance from a fireball of a nuclear explosion, the resulting shutter time is calculated. Existing protective devices, such as PLZT have a shutter time around 0.1 ms. A complete blockage of light cannot yet be realized technically.

4 CONCLUSIONS

Night operations is a goal for many people, but to do this, certain devices must be employed to help the aircrew, such as NVG, LLLTV or FLIR. These systems are expensive and difficult to integrate in modern aircraft, where other systems of higher priority are already present for daylight operations. Nevertheless, the trend is to use such systems to extend the fighter operations in the realm of night flying and fighting. The large number of specialists and manufacturers of nightrelevant sensors prove this fact.

On the other hand, the use of HMD, which already looks like present helmet systems, with almost the same weight, are coming to their final state of development. Combined with a HUD system, this is regarded as the future standard of aircraft equipment.

A system which includes HMD/S, night vision capabilities, which assures chemical protection and nuclear flash or intense laser light protection, with a light weight does not yet exist, but technological issues are answering to some of those problems.

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     H.L. TASK - D.F. KOCIAN - J.H. BRINDLE

Applications

Display Technologies	Full range of ambient (front cockpit)												Restricted range of ambient (rear cockpit)							
	Video HUD	Vector-graphic HUD	Video HDD	Vector-graphic HDD	Video HMS	Vector-graphic HMS	Vector-graphic MMD	Message MMD	Message Keyboard	Discrete Keyboard	Message Alphanumeric	Discrete Alphanumeric	Video HDD	Vector-graphic HDD	Vector-graphic MMD	Message MMD	Message Keyboard	Discrete Keyboard	Message Alphanumeric	Discrete Alphanumeric
CRT	1	1	1	1	1	1	1	1	5	5	5	5	1	1	1	1	5	5	5	5
VFD	5	5	5	5	5	4	4	3	3	3	3	3	5	5	4	3	3	3	3	3
LCD	3	3	3	3	3	3	3	3	3	3	2	1	3	3	3	3	3	3	2	1
PDP	5	5	5	5	5	5	5	5	5	5	5	5	5	1	1	1	1	2	1	2
LED	5	5	5	4	5	3	3	3	3	3	2	1	5	2	2	2	2	2	1	1
EL	5	4	4	3	3	3	3	3	3	3	3	2	3	3	3	3	2	2	2	2
ECD	5	5	5	5	5	4	4	4	4	3	3	2	5	5	4	4	4	3	3	2

1 - Technology is now used in this application.

2 - Technology is qualified for this application.

3 - Technology could be qualified for this application in 5 years.

4 - Use of technology for this application is possible in longer time frame.

5 - Technology unlikely to find use here.

FIG . 1 :   APPLICATIONS   ASSESSMENT
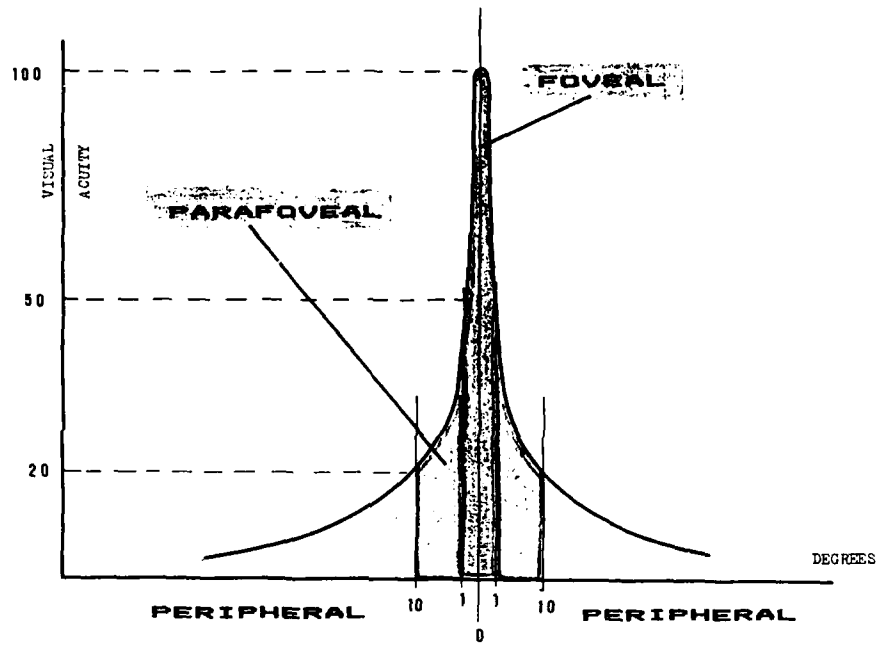
FIG . 2 : HUMAN VISUAL ACUITY
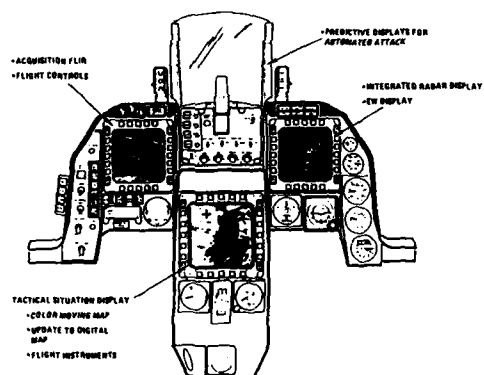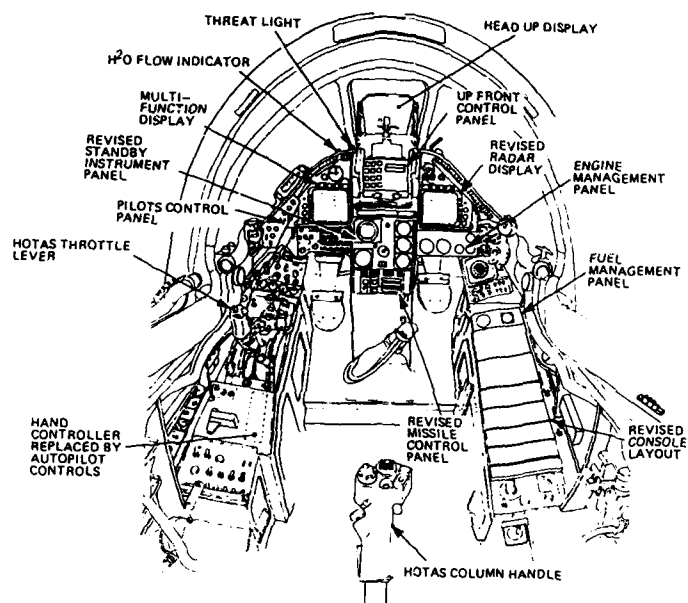
THREAT LIGHT

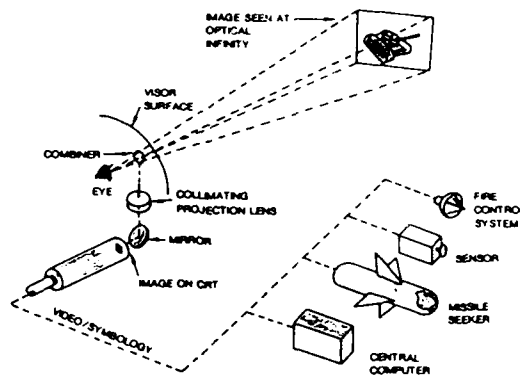HEAD UP DISPLAY

H²O FLOW INDICATOR

MULTI-
FUNCTION
DISPLAY

UP FRONT
CONTROL
PANEL

REVISED
STANDBY
INSTRUMENT
PANEL

REVISED
RADAR
DISPLAY

ENGINE
MANAGEMENT
PANEL

PILOTS CONTROL
PANEL

HOTAS THROTTLE
LEVER

FUEL
MANAGEMENT
PANEL

HAND
CONTROLLER
REPLACED BY
AUTOPILOT
CONTROLS

REVISED
MISSILE
CONTROL
PANEL

REVISED
CONSOLE
LAYOUT

HOTAS COLUMN HANDLE

•PREDICTIVE DISPLAYS FOR
AUTOMATED ATTACK

•ACQUISITION FLIR

•FLIGHT CONTROLS

•INTEGRATED RADAR DISPLAY

•EW DISPLAY

TACTICAL SITUATION DISPLAY

•COLOR MOVING MAP

•UPDATE TO DIGITAL
MAP

•FLIGHT INSTRUMENTS

FIG. 3 : PRESENT COCKPITS

FIG. 4 : HELMET MOUNTED DISPLAY CONCEPT

|	
SIZE / WEIGHT	IMAGE TO GHOST RATIO
CENTER OF GRAVITY	COLOR / COLOR CONTRAST
MONOCULAR VS. BINOCULAR	MODULATION TRANSFER FUNCTION
EXIT PUPIL	IMAGE SOURCE QUALITY
EYE RELIEF	ROLL STABILISATION COMPATIBILITY
APPARENT FIELD OF VIEW	COMBINER REFLECTIVITY/TRANSMISSIVITY
COLLIMATION	SYSTEM TRANSMISSION EFFICIENCY
DISTORSION	SAFETY

FIG. 5 : HMD DESIGN PARAMETERS
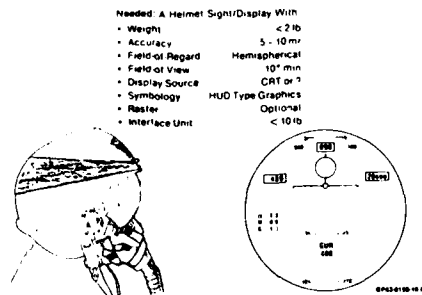
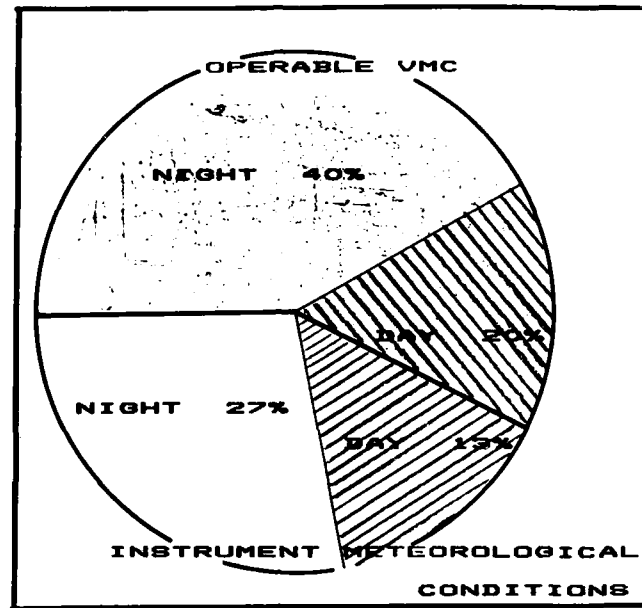FIG. 5 : HMD REQUIREMENTS

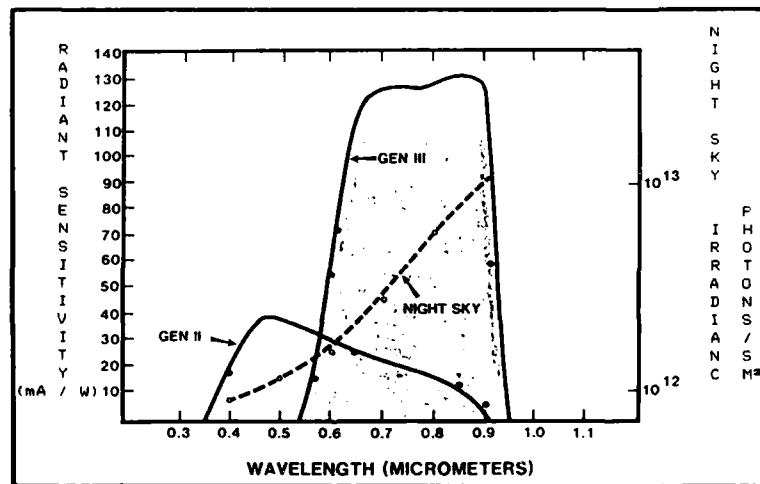FIG. 6 : WEATHER CENTRAL EUROPE WINTER

FIG. 7 : SENSIBILITIES OF GEN II AND GEN III PHOTOCATHODES
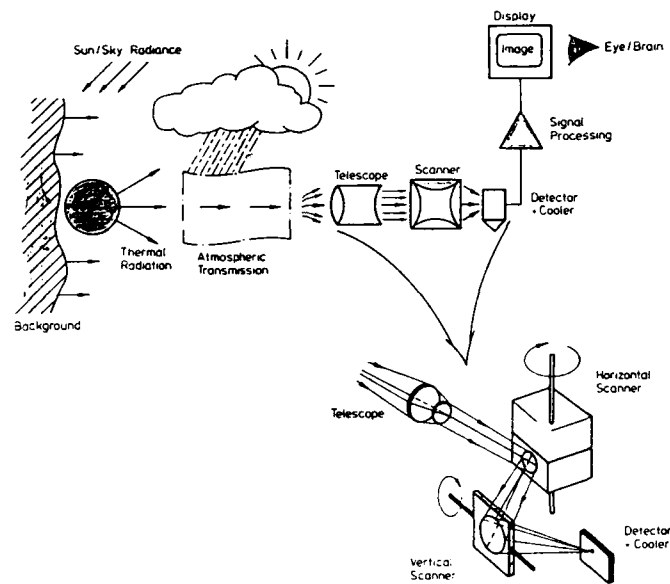
FIG. 8 : SCHEMATIC SET-UP OF THE THERMAL IMAGER COMPONENTS AND
THE IR RADIATION WITH THE ATMOSPHERIC TRANSMISSION

FIG. 9 : OCULAR EFFECTS VERSUS RANGE

SELECTIVE BIBLIOGRAPHY

This bibliography with abstracts has been prepared to support
AGARD Lecture Series No. 156 by the Scientific and Technical
Information Division of the U.S. National Aeronautics and Space
Administration, Washington, D.C., in consultation with the
Lecture Series Director, Col. L. Simonsen, RDAF Skrydstrup,
Denmark.

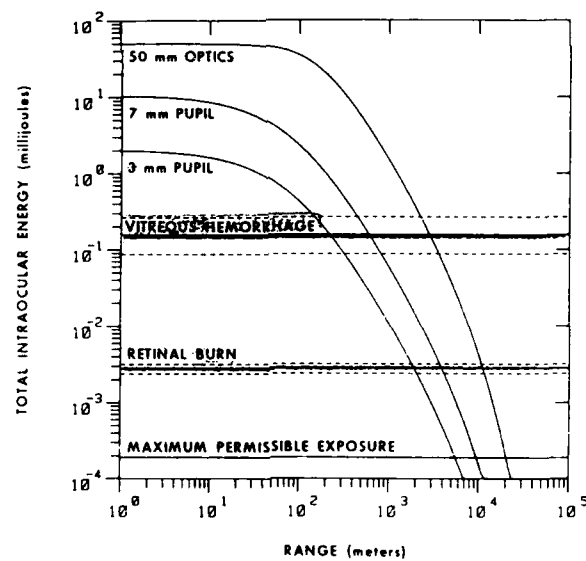UTTL: Guidance-Control-Navigation Automation for Night All-Weather Tactical Operations CORP: Advisory Group for Aerospace Research and Development, Neuilly-Sur-Seine (France). CSS: (Guidance and Control Panel.) The 40th Guidance and Control Panel Symposium was held at The Hague, Netherlands, 21-24 May 1985

ANN: The components, functions, and systems integration required to support the evolution of alternative guidance/navigation systems capable of enabling effective and routine night all-weather operations are discussed. Papers are organized under the following headings: operational requirements, systems concepts and integration issues, man-machine interface, terrain reference systems, and mission applications. For individual titles see N86-26317 through N86-26327.

RPT#: AGARD-CP-387 ISBN-92-835-0381-3 AD-A163072 85/10/00 86N26316

UTTL: Aerospace Behavioral Engineering Technology Conference, 4th, Long Beach, CA, October 14-17, 1985, Proceedings Conference sponsored by SAE. Warrendale, PA, Society of Automotive Engineers, Inc., 1985, 444 p. For individual items see A86-35427 to A86-35458.

ABS: Papers are presented on assessing human fitness and performance; the use of simulation as a cockpit design tool; the man-machine interface; the Space Station; and human performance. Consideration is given to advanced transport aircraft technology; operator workload analysis; rotorcraft missions; the pilot in the operational loop; and flight crew training. Topics also discussed include cockpit communications; color displays; commercial air transport and general aviation operations; and space and military operations.

RPT#: SAE P-168 85/00/00 86A35426

UTTL: Activities report on physical and psychological health of flying personnel CORP: National Aerospace Medical Centre, Soesterberg (Netherlands).

ABS: Activities concerning the physical and psychological health of flying personnel are summarized. A human centrifuge; anthropometric measurements on adolescents; F-16 pilot EEG's; and motion perception sensations with peripherally offered visual stimuli are discussed. Research was done on Meniere patients and rheo-encephalographics. Computerized psychodiagnostic methods for pilot and driver aptitude judgements were developed. Airbus cockpit certification methods were evaluated.

RPT#: ETN-86-97385 84/00/00 86N32093

UTTL: Advances in flight simulation - visual and motion systems; Proceedings of the International Conference, London, England, Apr. 29-May 1, 1986 Conference sponsored by the Royal Aeronautical Society. London, Royal Aeronautical Society, 1986. 346 p. For individual items see A87-44709 to A87-44728.

ABS: Papers are presented on air-to-air refueling simulation; the effectiveness of flight simulation in training KC-10 pilots in receiver refueling; applications of low cost visual simulation for basic pilot training; vestibular models for design and evaluation of flight simulator motion; the design of motion simulation software with digital filtering techniques; and motion software for a research flight simulator. Topics discussed include the fundamentals of simulator cockpit motion generation; requirements for effective flight simulator displays; visual cuing requirements in flight simulation; optical information for flight simulation; and the integration of a six-axis motion system and a wide angle visual system inside a dome. Consideration is given to simulator sickness; FLIR simulation in pilot training; visual systems development; area-of-interest displays using laser illumination; engineering and human visual issues in the development of a fiber-optic helmet mounted display; and training perceptual-motor skills. 86/00/00 87A44708

AUTH: A/ABBOTT, TERENCE S.; B/STEINMETZ, GEORGE G. CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

UTTL: Integration of altitude and airspeed information into a primary flight display via moving-tape formats

ABS: A ground-based aircraft simulation study was conducted to determine the effect on pilot performance of replacing the electromechanical altimeter and airspeed indicators with electronically generated representations integrated into the primary flight display via moving-tape (linear moving scale) formats. Several key factors relating to moving-tape formats were examined during the study: tape centering, secondary (trend) information, and tape orientation. The factor of centering refers to whether the tape was centered about the actual airspeed or altitude or about some defined reference value. Tape orientation refers to whether the values represented are arranged in either descending or ascending order. Six pilots participated in this study, with each subject performing 18 runs along a single, known flight profile. Subjective results indicated that the

moving-tape formats were generally better than that of the conventional instruments. They also indicated that an actual-centered fixed pointer was preferred to a reference-centered pointer. Performance data for a visual secondary task showed that formats not containing trend information produced better performance; however, no difference was noted in airspeed tracking or altitude tracking performance. Regarding tape orientation, subjective comments indicated that there was lower work load and better performance when the airspeed tape had the high numbers at the top.

RPT#: NASA-TM-89064 L-16221 NAS 1.15:89064 87/04/00
87N20265

UTTL: Integration of altitude and airspeed information into a primary flight display via moving-tape formats: Evaluation during random tracking task
AUTH: A/ABBOTT, TERENCE S.; B/NATAUPSKY, MARK; C/STEINMETZ, GEORGE G. CORP: National Aeronautics and Space Administration. Langley Research Center. Hampton, Va.
ABS: A ground-based aircraft simulation study was conducted to determine the effects on pilot preference and performance of integrating airspeed and altitude information into an advanced electronic primary flight display via moving-tape (linear moving scale) formats. Several key issues relating to the implementation of moving-tape formats were examined in this study: tape centering, tape orientation, and trend information. The factor of centering refers to whether the tape was centered about the actual airspeed or altitude or centered about some other defined reference value. Tape orientation refers to whether the represented values are arranged in descending or ascending order. Two pilots participated in this study, with each performing 32 runs along seemingly random, previously unknown flight profiles. The data taken, analyzed, and presented consisted of path performance parameters, pilot-control inputs, and electrical brain response measurements.

RPT#: NASA-TM-4010 L-16309 NAS 1.15:4010 87/09/00
87N27665

UTTL: Peripheral vision displays: The future
AUTH: A/ASSENHEIM, H. M. CORP: Garrett Mfg. Ltd., Rexdale (Ontario). In NASA. Dryden Flight Research Center Peripheral Vision Horizon Display (PVHD) p 117-124 (SEE N85-10044 01-06)
ABS: Several areas of research relating to peripheral vision displays used by aircraft pilots are outlined: Various fiber optics, display color, and holography. Various

capacities and specifications of gas and solid state lasers are enumerated. These lasers are potential sources of green light for the peripheral vision displays. The relative radiance required for rod and cone vision at different wavelengths is presented graphically. Calculated and measured retinal sensitivities (foveal and peripheral) are given for wavelength produced by various lasers. 84/04/00
85N10058

UTTL: AOI displays using laser illumination
AUTH: A/BARBER, B
PAA: A/(Rediffusion Simulation, Ltd., Crawley, England)
IN: Advances in flight simulation - visual and motion systems; Proceedings of the International Conference, London, England, Apr. 29-May 1, 1986 (A87-44708 19-53). London, Royal Aeronautical Society. 1986. p. 272-294.
ABS: The development and design of a helmet-mounted laser projector are described. The projector design features are: laser illumination, two channel eye-coupled area-of-interest (AOI) visual display, close proximity, and exit pupil and eye point. The helmet-mounted optics include galvanometer driven mirrors which perform vertical scanning and deflect the projected rasters vertically and horizontally. The display system of the helmet-mounted laser projector is coupled to the visual technology research simulator flight computer and receives video from the two channels of the image generator. Consideration is given to the system's line image generator, fiber optic links, head and eye trackers, computer-image generation, and visual processor. The assembly of the helmet and the calibration of the head and eye trackers are discussed. The performance of the projector is evaluated, and it is observed that the system performs well. An alternative design for an AOI projector requirement is proposed. 86/00/00
87A44726

UTTL: Dual-task timesharing using a projected attitude display (Malcolm horizon)
AUTH: A/BELLENKES, A. H. CORP: Naval Aerospace Medical Research Lab., Pensacola, Fla.
ABS: In order to optimize timesharing and facilitate performance in the high workload environment of the modern cockpit, a peripheral vision horizon device (PVHD) has been developed which can present aircraft attitude data to the visual periphery; an area reported to be highly sensitive to the perception of information regarding orientation in space. A great deal of subjective evidence gathered from simulator

UTTL: A peripheral integrated status display - Is it really giving the 'big picture' or is it a miniseries?
AUTH: A/BERINGER, D. B.
PAA: A/(Wisconsin, University, Madison)   IN: Human Factors Society, Annual Meeting, 29th, Baltimore, MD, September 29-October 3, 1985, Proceedings. Volume 1 (A86-33776 15-53). Santa Monica, CA, Human Factors Society, 1985, p. 304-307.
ABS: Much effort has been directed towards the creation of effective integrated displays for vehicle or system control. These efforts have generally been aimed at 'primary' instruments or indices of system performance and only comparatively recently have secondary indices received similar attention. Each group of indices, however, has generally been kept separate, resulting in systems having multiple nonintegrated integrated displays. A method is proposed whereby these may be combined within a single instrument or 'integrated' integrated display. This method is based upon the use of spatial cues created by regular versus irregular polygons. A major question at issue is whether such a display created by regular versus irregular polygons. A major question at issue is whether such a display constitutes a single integrated shape or merely an assembly of subshapes that are serially scanned.
85/00/00   86A33791

UTTL: A graphics environment supporting the rapid prototyping of pictorial cockpit displays
AUTH: A/BRAATEN, ALAN J.   CORP: Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.   CSS: (School of Engineering.)
ABS: Attention was focused on the interactive construction of pictorial type cockpit displays from libraries of cockpit displays and symbology. Implementation was based on an object-oriented programming paradigm. This approach provided a natural and consistent means of mapping abstract design specifications into functional software. Implementation was supported by an object-oriented extension to the C programming language. Although this investigation addressed a specific application, the resulting graphic environment is applicable to other areas requiring the rapid prototyping of pictorial displays.
RPT#: AD-A178636 AFIT/GCS/MA/86D-1   86/12/00   87N23182

UTTL: Visual and spectroradiometric performance criteria for Night Vision Goggles (NVG) compatible aircraft interior lighting
AUTH: A/BREITMAIER, W. A.; B/REETZ, F., III   CORP: Naval Air Development Center, Warminster, Pa.   In AGARD Visual Protection and Enhancement 11 p (SEE N86-26802

and operational test flights has lent support to the efficacy of this device in improving performance. However, this capability has yet to be verified by controlled laboratory testing. Two horizon sizes were evaluated: one with dimensions similar to that found in an aircraft instrument panel and the other extending out to the visual periphery. The objective of this study was to determine whether dual-task performance could be improved by using the large projected horizon vs. a more conventional short horizon. The findings indicated that the PVHD allowed subjects to perform the foveated mental arithmetic task while simultaneously controlling the orientation of the horizon. PVHD root mean square (RMS) error, and mental arithmetic speed/accuracy data were found to be superior when subjects used the extended vs. the short horizon for tracking. These findings suggest that the PVHD permitted individuals to process the two sets of visual information in parallel, thereby improving performance on both.
RPT#: AD-A150789 NAMRL-1310   84/11/00   85N24750

UTTL: A peripheral integrated system status display - Figural goodness or proximity effects?
AUTH: A/BERINGER, D. B.
PAA: A/(Wisconsin, University, Madison)   IN: Symposium on Aviation Psychology, 3rd, Columbus, OH, April 22-25, 1985, Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985, p. 183-187.
ABS: Certain problems arising in connection with peripheral or secondary displays are examined. Secondary display systems usually require additional visual scanning beyond the primary displays for system control. These secondary devices generally require the diversion of attention from primary displays used for flight control. The occurring lapses in primary task performance may contribute to a degradation in system performance. Such a degradation can be especially threatening in aviation systems used by commercial carriers. Attention is, therefore, given to alternate means of information display and their underlying desired qualities. 'Figural' displays are considered along with integrated displays. the present application used for experimentation, and the experimental examination of the display. The evaluated results suggest that the use of an integrated analog display allowing some shape or figural processing can be beneficial.   85/00/00   86A29870

17-52)
ABS: A draft military specification for NVG-compatible aircraft interior lighting was developed. The specification is based on the utilization of a specific type of NVG, the AN/AVS-6 Aviators Night Vision Imaging System (ANVIS). The performance requirements and testing methodology established in the specification and the rationale for developing these requirements are described. The performance requirements are affected by three factors: luminance, chromaticity, and ANVIS compatibility. Luminance requirements do not change drastically from the requirements that presently exist for interior lighting. However, the chromaticity requirements of green for primary and secondary lighting, and yellow for both master caution and warning indicators are different from those that presently exist. The reason for this change is that any lighting with a significant amount of red energy cannot be used in a cockpit that is required to be ANVIS compatible. The implications for this new color design for cockpit lighting are discussed together with the rationale for the chromaticity coordinates and limits chosen. ANVIS compatibility is defined in terms of the spectral sensitivity of the ANVIS and the combination of spectral radiance of the cockpit lighting and the outside world night radiance. Quantitative testing methodology for determining ANVIS compatibility of cockpit lighting is also discussed. A thorough description of all analytic and laboratory studies performed in support of this specification development is presented. 85/12/00 86N26807

UTTL: Electronic display luminance and grey scale control
AUTH: A/BURNETTE, K. T.
PAA: A/(Burnette Engineering, Fairborn, OH) IN: NAECON 1985; Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 20-24, 1985. Volume 2 (A86-28326 12-04). New York, Institute of Electrical and Electronics Engineers, 1985, p. 1500-1510.
ABS: The role that luminance plays in making information depicted on military aircraft video displays both perceptible and interpretable by a pilot is explored. Particular design criteria issues are investigated that involve electronic display luminance and grey scale control: display luminance uniformity, sensor/video system signal transfer characteristics, display picture grey shade content, and the effects of cockpit illumination and glare source viewing conditions. 85/00/00 86A28505

UTTL: Multi-color display design criteria
AUTH: A/BURNETTE, K. T.
PAA: A/(Burnette Engineering, Fairborn, OH) IN: NAECON 1984; Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 21-25, 1984. Volume 2 (A85-44976 21-01). New York, IEEE, 1984. p. 1348-1363.
ABS: The color design criteria which must be met to apply multicolor displays in bubble canopy aircraft illumination environments are discussed. The effectiveness of existing color characterization techniques is evaluated, and a theory to predict color perception in a changing chrominance illumination environment is proposed. Color uniformity criteria which are needed to purify signal colors in multicolor dot matrix displays are also discussed. 84/00/00 85A45160

UTTL: Eye-controlled switching for crew station design
AUTH: A/CALHOUN, G. L.; B/BOFF, K. R.; C/ARBAK, C. J.
PAA: B/(USAF, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH); C/(Systems Research Laboratories, Inc., Dayton, OH) IN: Human Factors Society, Annual Meeting, 28th, San Antonio, TX, October 22-26, 1984, Proceedings. Volume 1 (A86-23701 09-54). Santa Monica, CA, Human Factors Society, 1984. p. 258-262.
ABS: Integration of eye and head position monitoring devices may enable practical control of systems using the operator's eye line-of-sight (LOS) under conditions of free head and eye movement. This paper describes the components of an eye-control system developed to examine the use of eye LOS as an alternate control interface for crew station design. The implications of the performance of this system to the implementation of eye-controlled switching are discussed. 84/00/00 86A23711

UTTL: The evolution of the cockpit displays in commercial airlines
AUTH: A/CASTIES, J.
PAA: A/(Thomson-CSF, Division Equipements Avioniques, Melakoff, France) (Association Internationale des Instituts de Navigation, Congres International, 5th, Tokyo, Japan, Oct. 1-5, 1985) Navigation (Paris) (ISSN 0028-1530), vol. 33, Oct. 1985, p. 399-408. In French.
ABS: The development of high resolution CRTs has led to the installation of digitized information displays in instrument panels of passenger aircraft. Integrated circuits provided the necessary reliability and image clarity for ensuring flight safety. The devices were first used in simulators for the Concorde and then for

UTTL: Evaluation of a pilot's line-of-sight using ultrasonic measurements
AUTH: A/CHRISTIANSEN, HERMANN
PAA: A/(AEG-AG, Wedel, West Germany) European Rotorcraft Forum, 11th, London, England, Sept. 10-13, 1985. Paper. 12 p.
ABS: The task of evaluating a pilot's line-of-sight by determining the three angles of movement (azimuth, elevation, and roll) is described. A solution is described which is based on the measurement of the transmission time of ultrasonic signals between transmitters mounted on the cockpit structure and receivers on the pilot's helmet. A description is given of the complete system which includes a helmet-mounted display, a line-of-sight locator, and a three-axis controlled platform. Technical problems such as immunity from echoes and interference, immunity from cockpit noise, and air temperature and actual speed of sound are considered as well.
85/09/00 87A48922

UTTL: Direct view helmet mounted telescope
AUTH: A/CONNON, T. R. CORP: Department of the Air Force. Washington, D.C.
ABS: This patent is an improved helmet including an optical system whereby the wearer may telescopically acquire an image of a field of view, which comprises a telescope retractably mounted to the helmet by means of a two-part ringed boom, one end of which is pivotaly attached to the side of the helmet, and the other end of which supports the telescope via a rotatable and adjustable mounting whereby the telescope may be conveniently moved from a stored position beside the helmet to an operative position in front of the wearer's eye, and aligned and focused in the operative position.
RPT#: AD-D012257 US-PATENT-4,577,347 US-PATENT-APPL-SN-634247 US-PATENT-CLASS 2-6
86/03/25 86N32421

UTTL: The Icarus multicolor visual display system for fighter aircraft
AUTH: A/CREUTIN, G. Navigation (Paris) (ISSN 0028-1530), vol. 33, July 1985, p. 289-297. In French.
ABS: The multimodal visual display screen installed in the Mirage 2000 fighter for combined navigation and stores control during low-altitude flight is described. The display is driven by an integrated digital system multiplexing data from terrain-following radar, and dual inertial systems, and provides head-up and head-down displays. The copilot in the rear seat receives only a head-down display. The

flight hardware on the 757 and 767 aircraft. Shadow-mask technology, being implemented for the new generation of Airbus vehicles, has sufficient stability due to the electron gun alignment configuration that the technology is being tested for use in helicopters, which experience high vibration levels. The new avionics displays furnish navigation, aircraft control and flight management information, including digitized maps, meteorological and radar data. Data can be split into two screens, one for status displays and another for checklist procedures for, e.g., compensating for a malfunction. The avionics on the Airbus 320, scheduled for delivery in 1988, will feature a common computer for the displays and a mini-controller for directing the aircraft. Directions being taken to introduce AI into the avionics are briefly discussed. 85/10/00 86A18694

UTTL: Advanced concepts flight simulation facility
AUTH: A/CHAPPELL, S. L.; B/SEXTON, G. A.
PAA: A/(Informatics General Corp., Marietta, GA); B/(Lockheed-Georgia Co., Marietta, GA) IN: Symposium on Aviation Psychology, 3rd, Columbus, OH, April 22-25, 1985, Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985, p. 575-582.
ABS: Three identical Advanced Concepts Flight Simulation Facilities have been completed by NASA together with the Lockheed-Georgia Company. These simulation facilities, based on projected air travel needs and technology available for flight by 1995, have three components: (1) the Advanced Concepts Flight Station (ACFS); (2) an integrated air traffic control simulation; and (3) experimenter/observer stations. The ACFS is based on a hypothetical wide-body composite airframe propelled by two turbo-fan engines that has a range of 2500 miles and carries 200 passengers. The optimized airframe design produces a negative static margin and relies upon a three-axis stability augmentation system for manual aircraft control. Features incorporated into its components include: voice-operated cathode ray tube displays of flight systems information, clearance print-outs, cockpit traffic displays, current databases containing navigational charts, fuel-efficient autopilot control from takeoff to touchdown, and an outside visual scene withy variable weather conditions. It has been shown that this cockpit is a versatile test-bed for studying displays, controls, procedures, and crew management in a full-mission context. 85/00/00 86A29916

system/sensor tracker system; master modes that configure flight controls and mission avionics; a modified helmet mounted sight; improved multifunction display capability; a voice interactive command system; ride qualities during automated weapon delivery; a color moving map; an advanced digital map display; and a g-induced loss-of-consciousness and spatial disorientation autorecovery system. 86/00/00 87A16787

UTTL: Flying with night-goggles and head-down display at night
AUTH: A/DANNEBERG, E.
PAA: A/(Deutsche Forschungs- und Versuchsanstalt fuer Luftund Raumfahrt, Institut fuer Flugfuehrung, Brunswick, West Germany) (European Rotorcraft and Powered Lift Aircraft Forum, 9th, Stresa, Italy, Sept. 13-15, 1983) Vertica (ISSN 0360-5450), vol. 8, no. 4, 1984, p. 423-431.

ABS: The results of an optimization study of the components and systems suitable for efficient operation of the helicopter crew in low-level flights at night are outlined. The systems discussed are: electronic head-down display, helmet-mounted display, night goggles, low light level TV, and forward-looking IR cameras. Pilot's eye movements were recorded during flights over an obstacle and over familiar and unfamiliar routes; the responses indicate the desirability of integrating the head-down display in the lower part of the instrumental panel. Moreover, it is inferred that during flights over an unfamiliar route it is beneficial for the pilot to concentrate on the aircraft control while the copilot is concerned with navigation. 84/00/00 85A30944

UTTL: Evaluation of helmet display formats
AUTH: A/DE MAIO, J.; B/HARMAN, C.; C/STRYBEL, T.; D/PENNER, R.; E/BROCK, J.
PAA: E/(Honeywell Systems and Research Center, Minneapolis, MN) IN: NAECON 1985; Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 20-24, 1985. Volume 2 (A86-28326 12-04). New York, Institute of Electrical and Electronics Engineers, 1985, p. 929-936.

ABS: Research was performed to evaluate the readability of flight control, navigation, and sensor pointing symbology on monocular, helmet-mounted display. Display readability was evaluated under two task-loading conditions: (1) single-task display reading only; and (2) multitask, head-down panel I/O task plus head-up target detection plus display reading. Two helmet display formats were evaluated.

terrain-following radar permits automated low-altitude flight at optimized velocities, and is subject to manual override. The pilot is presented with a tricolor map of the terrain, with options for the area ahead, below and behind, and calculations of projected flight time and fuel consumption for different flight paths expressed symbolically. The system was devised to lower the pilot workload, enhance flight safety and allow the pilot and navigator to keep watch on the sky. 85/07/00 85A44051

UTTL: The effect of using speech generation and recognition systems on the performance of discrete tasks
AUTH: A/DAMOS, D.
PAA: A/(Arizona State University, Tempe) IN: Symposium on Aviation Psychology, 3rd, Columbus, OH, April 22-25, 1985. Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985. p. 127-133.

ABS: Twenty-eight male subjects performed a task combination consisting of a spatial short-term memory task and a verbal short-term memory task. Stimuli for the verbal task could be presented either visually on a CRT or auditorily through headphones. Subjects responded to the verbal task either manually using a keypad or vocally using a voice recognition system. Analyses revealed significantly more accurate dual-task performance with auditory rather than visual stimuli. However, there was no significant difference between speech responses and manual responses on measures of either speed or accuracy. 85/00/00 86A29863

UTTL: Pilot vehicle interface on the advanced fighter technology integration F-16
AUTH: A/DANA, W. H.; B/SMITH, W. B.; C/HOWARD, J. D.
PAA: A/(NASA, Flight Research Center, Edwards AFB, CA); B/(General Dynamics Corp., Fort Worth, TX); C/(USAF, Flight Test Center, Edwards AFB, CA) CORP: National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.; General Dynamics Corp., Fort Worth, Tex.; Air Force Flight Test Center, Edwards AFB, Calif. IN: NAECON 1986; Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 19-23, 1986. Volume 2 (A87-16726 05-01). New York, Institute of Electrical and Electronics Engineers, 1986, p. 595-607.

ABS: This paper focuses on the work load aspects of the pilot vehicle interface in regard to the new technologies tested during AMAS Phase II. Subjects discussed in this paper include: a wide field-of-view head-up display; automated maneuvering attack

Configuration 1 was essentially of current attack helicopter symbology. Configuration 1 used reformatted symbology designed to reduce obscuration of the outside visual scene and to enhance readability. In the single-task conditions subjects scanned a static display for a target deviation of one parameter from a pre-assigned value. Dependent measures were error rate and reaction time. In the multi-task experiment, reaction time was measured from completion of the detection task. Display reading accuracy was high for both display configurations. Results are discussed in terms of display readability. 85/00/00 86A28440

UTTL: Report on a visit to England
AUTH: A/DEREFELDT, G.; B/BERGGRUND, U. CORP: Research Inst. of National Defence, Stockholm (Sweden). Proc. of Nato Workshop on Color Coded VS Monochrome Electron. Displays, Farnborough, England, 28 Feb. - 1 Mar. 1984
ABS: Color and monochrome display cost and system effectiveness; color displays in aircraft cockpits; digitally generated maps for aircraft; subjective reactions to color displays; and raster graphics were discussed.
RPT#: FOA-C5-85-0006-H2 ISSN-0347-7665 85/03/00 86N10364

UTTL: Human factors in aviation. I
AUTH: A/EDWARDS, E. Aerospace (UK) (ISSN 0305-0831), vol. 12, June-July 1985, p. 13-17.
ABS: The ergonomic factors influencing the design of cockpit instruments, control devices and accommodations are discussed, on the basis of data accumulated in the fields of perceptual psychology, anthropometry, and cognitive psychology. The design of cockpit displays is noted to call for careful attention to the relevant human perceptual processes, irrespective of the technical problems associated with the instrument's production. Attention must also be given to cockpit temperature control and especially to cockpit lighting. 85/07/00 85A39368

UTTL: Influence of a perspective cockpit traffic display format on pilot avoidance maneuvers
AUTH: A/ELLIS, S. R.; B/MCGREEVY, M. W.; C/HITCHCOCK, R. J.
PAA: C/(San Jose State Univ.) CORP: National Aeronautics and Space Administration. Ames Research Center. Moffett Field, Calif. In AGARD Human Factors Considerations in High Performance Aircraft 9 p (SEE N85-19853 10-54)

ABS: Perspective projections of cockpit displays of traffic information (CDTI) on CRTs to present vertical separation information to airline pilots were examined. The perspective projection was compared with plan view projections of the same air traffic situations. Comparison of the pilots' avoidance maneuvers made when using the perspective display with those made while using more the conventional plan view display showed that pilots maneuvered somewhat earlier with perspective displays. With the perspective display, they maneuvered more frequently in the vertical dimension. The bias to maneuver horizontally probably reflected the poorer presentation of vertical separation on previously used plan view traffic displays. The avoidance decisions made by pilots using both perspective and plan view displays shows fewer unsuccessful maneuvers and fewer maneuvers producing spacing violations with the perspective format. 84/11/00 85N19668

UTTL: Perspective traffic display format and airline pilot traffic avoidance
AUTH: A/ELLIS, STEPHEN R.; B/MCGREEVY, MICHAEL W.; C/HITCHCOCK, ROBERT J.
PAA: B/(NASA. Ames Research Center. Moffett Field. California. University. Berkeley); C/(San Jose State University, CA) CORP: National Aeronautics and Space Administration. Ames Research Center. Moffett Field, Calif.; California Univ., Berkeley.; San Jose State Univ., Calif. Human Factors (ISSN 0018-7208), vol. 29, Aug. 1987, p. 371-382.
ABS: Part-task experiments have examined perspective projections of cockpit displays of traffic information as a means of presenting aircraft separation information to airline pilots. Ten airline pilots served as subjects in an experiment comparing the perspective projection with plan-view projections of the same air traffic situations. The pilots' task was to monitor the traffic display in order to decide if an avoidance maneuver was needed. Pilots took more time to select avoidance maneuvers with a conventional plan-view display than with an experimental perspective display. In contrast to previous results, if the pilots selected a maneuver with the perspective display, they were more likely to choose one with a vertical component. Tabulation of the outcomes of their initial avoidance decisions with both perspective and plan-view displays showed that they were more likely to achieve required separation with maneuvers chosen with the aid of perspective displays. 87/08/00 88A12639

UTTL: Cockpit automation requirements derived from mission functions data

AUTH: A/FAULKNER, B.; B/SEIFERT, R.; C/RICHTER, K. D.
CORP: Messerschmitt-Boelkow-Blohm G.m.b.H., Munich (West Germany).   In AGARD Guidance-Control-Navigation Automation for Night All-Weather Tactical Operations 7 p (SEE N86-26316 17-04)

ABS: Program activities directed towards the development of a system engineering concept for the design of the man-machine interface are summarized. The problem was approached from an operational and human task point of view. The first phase included the development of: (1) a mission task list for selected mission and weapon systems; (2) a method for rating the relative importance of each of the tasks related (a) to the frequency of occurrence, (b) to mission effectiveness, and (c) to flight safety; (3) criteria and/or categories for automation at the man-machine interface, against which the individual mission tasks could be rated; and (4) a method for rating the mission tasks in relation to the automation categories derived. 85/10/00 86N26318

UTTL: A cost-effective night attack system for ground attack aircraft

AUTH: A/FISHER, J. F.; B/SLEIGHT, G. R.   CORP: Marconi Avionics Ltd., Rochester (England).   In AGARD Guidance-Control-Navigation Automation for Night All-Weather Tactical Operations 8 p (SEE N86-26316 17-04)

ABS: Current ground attack fighters have a good day visual flight rule (VFR) capability. However, they are generally ineffective at night. GEC Avionics have developed a simple integrated night vision system which allows a pilot to operate effectively at high speed and low level. The system uses a fixed forward-looking FLIR sensor to display imagery to the pilot on a raster head-up display. This allows him to terrain-follow and acquire targets. He then uses a touch-sensitive head down display to designate targets to his weapon system for subsequent attack. The pilot is also equipped with night vision goggles to permit hard maneuvering, and with a digital map to enable him to navigate flexibly. By designing the entire system as an integrated whole, cockpit workload is minimized. A series of flight trials has clearly proved the concept. The US Marine Corps AV-8B and RAF Harrier GR5 will soon be equipped with just such a system. 85/10/00 86N26317

UTTL: Flight evaluation of augmented controls for approach and landing of powered-lift aircraft

AUTH: A/FRANKLIN, J. A.; B/HYNES, C. S.; C/HARDY, G. H.; D/MARTIN, J. L.; E/INNIS, R. C.
PAA: E/(NASA, Ames Research Center, Moffett Field, CA)
CORP: National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.   (AIAA, Guidance, Navigation and Control Conference, Snowmass, CO, Aug. 19-21, 1985) Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 9, Sept.-Oct. 1986, p. 555-565.

ABS: Flight experiments were conducted with Ames Research Center's Quiet Short-Haul Research Aircraft to evaluate the influence of highly augmented control modes on the ability of pilots to execute precision instrument flight operations in the terminal area, particularly approaches to and landings on a short runway. The aircraft is a powered-lift, short-takeoff and landing configuration that is equipped with a modern digital fly-by-wire flight control system, a head-up display, and a solar head-down display that make it possible to investigate control concepts and display format and content for full envelope, powered-lift operation. Considerable attention has been devoted in this flight program to assessing flightpath and airspeed command and stabilization modes developed using nonlinear, inverse model-following methods. The primary benefit of this control concept was realized when the pilot was required to execute a complex transition and approach under instrument conditions and in the presence of a wide range of wind and turbulence conditions.
RPT#: AIAA PAPER 85-1944   86/10/00   87A17755

UTTL: Imaging sensors and displays; Proceedings of the Meeting, Los Angeles, CA, Jan. 13, 14, 1987

AUTH: A/FREEMAN, CHARLES F.
PAA: A/(U.S. Army. Center for Night Vision and Electro-Optics, Fort Belvoir, VA) Meeting sponsored by SPIE. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Volume 765), 1987, 139 p. No individual items are abstracted in this volume.

ABS: The present conference on the imaging technologies associated with electrooptic sensors considers topics in the research areas concerned with the human factors involved in such systems, the state-of-the-art technologies' character, novel and advanced imaging displays, and image display technologies specifically intended for IR projectors. Attention is given to the analysis of electroluminescent displays for stereographic video images, eye-limited display brightness and field-of-view parameters,

helmet-mounted infantry displays, temporal aspects of electrooptical imaging, a color laser microscope, the implementation of a sensitivity control function on a solid state imager chip, high resolution CRTs and MIM-diode LCDs, an IR-emitting CRT, IR image generation by thermoelectric elements, and IR transducer technology.
RPT#: SPIE-785   87/00/00   87A36539

UTTL: The super cockpit and its human factors challenges
AUTH: A/FURNESS, THOMAS A., III
PAA: A/(USAF, Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH) IN: Human Factors Society, Annual Meeting, 30th, Dayton, OH, Sept. 29-Oct. 3, 1986, Proceedings. Volume 1 (A87-33001 13-54) Santa Monica, CA, Human Factors Society, 1986, p. 48-52.
ABS: A revolutionary virtual crew station concept titled the 'Super Cockpit' is introduced with its applications and operational advantages. Unique aspects of the virtual information portrayal and interactive medium of the super cockpit are discussed leading to a need for new areas of human factors research and engineering.   86/00/00   87A33005

UTTL: Night vision support devices: Human engineering integration
AUTH: A/GENCO, L. V.   CORP: Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio.   In AGARD Visual Protection and Enhancement 8 p (SEE N86-26802 17-52)
ABS: Although NVGs extend the luminance range over which vision can be used, current AN/PVS systems require special cockpit lighting to be fully effective, reduce visual depth of field and diminish the field of view. All three of these factors are extremely important to pilots performing night operations. The results of several operationally oriented efforts conducted by the U.S. Air Force to improve visual performance, cockpit lighting, and flight information transfer in conjunction with the use of NVGs are described. The efforts include an operational definition of NVG compatible lighting, a recommended approach to improving depth of focus, an attempt to expand field of view, and a description of a NVG HUD using optically injected flight data. All efforts center around using or modifying current AN/PVS NVGs used by US forces.   85/12/00   86N26808

UTTL: Visual phenomena produced by binocularly disparate dynamic visual noise
AUTH: A/GERI, G. A.; B/ZEEVI, Y. Y.   CORP: Dayton Univ., Ohio.; Massachusetts Inst. of Tech., Cambridge.
ABS: The use of helmet mounted displays in flight simulation requires that different visual stimuli be presented to the two eyes. Such disparate stimulation may result in perceptual problems which could adversely affect simulator training. A series of four experiments addressed several perceptual problems associated with the use of binocularly disparate stimuli. The stimulus used in all four experiments was the dynamic visual noise (DVN) stereophenomenon produced by viewing a detuned television receiver with the input to one eye attenuated by a light filter. The result is the percept of several counterdirectional dot-planes separated in depth. The purpose of the basic visual research reported here is to further elucidate the visual mechanisms underlying movement aftereffects (Experiment 1), binocular rivalry (Experiment 2), perceived visual acceleration (Experiment 3), and vergence and accommodation to perceived depth (Experiment 4). Each of these phenomena was induced by a form free texture stimulus perceived as moving in planes located at various distances from the observer.
RPT#: AD-A154758 AFHRL-TP-85-4   85/05/00   85N32757

UTTL: The metamorphosis of the military aircraft cockpit
AUTH: A/GLICKSTEIN, I.
PAA: A/(IBM Corp., Federal Systems Div., Owego, NY)
Aerospace America (ISSN 0740-722X), vol. 23, Aug. 1985, p. 48-50, 52.
ABS: Advances in AI and automation technologies are enabling the development of the 'rational cockpit', which will adjust the pilot's role to one of a flight manager. Already, in the HH-60A Night Hawk Combat search and rescue helicopter, the crew serves as the interface between the helicopter and the avionics. The HH-60A CRTs display present combinations of sensor video, symbology and tabular data on pilot request. Conformal symbology and thermal imagery are generated in helmet mounted displays. The avionics system has reduced the HH-60A crew to two from four. Research continues on a 'pilot's associate' expert system which will handle routine tasks and those a human pilot cannot do, particularly aircraft systems status examinations. Combat maneuvers may also be programmed into the associate. The capabilities may be extended to present an artificial visual panorama in degraded visibility conditions and controls responsive to voice, touch, and eye and head positions.   85/08/00

85A42893

AUTH: A/GROSSMAN, J. D.

PAA: A/(U.S. Navy, Naval Weapons Center, China Lake, CA)

UTTL: Contemporary problems in airborne displays

IN: Advances in display technology III; Proceedings of the Meeting, Los Angeles, CA, January 18, 19, 1983 (A85-22588 09-31). Bellingham, WA, SPIE - The International Society for Optical Engineering. 1983. p. 29-31.

ABS: Certain problems arise in connection with current airborne displays. These problems are basically related to four primary factors. One factor is the rapid increase in the capability to collect and process large amounts of data, while a second factor is the need for increasingly precise information. Cockpit space restrictions represent another factor, and a diminishing gap between workload requirements and crew task load capabilities is a fourth factor. The problems encountered are discussed along with approaches for solving them. Attention is given to the employment of multifunction displays and controls, difficulties caused by a hierarchical rather than simultaneous display, a critical evaluation of voice interactive systems, advantages provided by integrated displays, the possibility that the integration of disparate functions may increase the operator's mental workload, developments related to precision and timeliness, sensor displays, and problems concerning the appropriate use of new technologies. 83/00/00

85A22593

AUTH: A/GUNTHER, MARTY

PAA: A/(Kaiser Aerospace and Electronics Corp., Kaiser Electronics Div., San Jose, CA) IN: Digital Avionics Systems Conference, 7th, Fort Worth, TX, Oct. 13-16, 1986, Proceedings (A87-31451 13-01). New York, Institute of Electrical and Electronics Engineers, Inc. 1986, p. 167-172.

UTTL: Advanced Helmet Integrated Display Systems

ABS: The Advanced Helmet Integrated Display Systems (AHIDS) developed by Kaiser Electronics are state-of-the-art displays which couple the pilot to the tactical situation and aircraft systems. Four helmet systems are currently in development including stroke, raster, and image intensifier display formats. When required, an accurate helmet tracking system provides the correct positioning of target cues and other flight critical position dependent information. The display systems incorporate a unique design concept in that a fully integrated helmet is molded around the optimum optical scheme. AHIDS demonstrate high optical

performance in helmets that are lightweight, maintain a low profile, have a tuned center of gravity, and provide the protection of current operational helmets. Since AHIDS are totally new, the design concept includes a modern aesthetic appearance with aerodynamic qualities that are compatible with canopy loss and high speed ejection. 86/00/00 87A31470

AUTH: A/GUTTMAN, JERRY CORP: Naval Air Development Center, Warminster, Pa. CSS: (Aircraft and Crew Systems Technology Directorate.)

UTTL: Evaluation of the F/A-18 head-up-display for recovery from unusual attitudes

ABS: Maintaining situational awareness is a critical task in piloting an aircraft. Focusing on spatial orientation, the attitude displays provide information necessary for the pilot to control the aircraft's position in space. In the F/A-18 aircraft the Head-Up-Display (HUD) is the primary attitude indicator. This study compared electrically drawn attitude direction indicator (ADI), the current F/A-18 HUD, and the concurrent use of the ADI and HUD for recovery from unusual attitudes. Results indicated significantly faster recovery times for the ADI. Reasons may be attributed to the superiority of the color coding of the ADI for sky and ground over the dashed and solid pitch lines used for ground/sky coding on the HUD format. Pilot preferences were split between using the ADI as a convenient crosscheck and reduction of visual workload when using the HUD and ADI concurrently compared to using the HUD alone. The results from this study, which employed an electrically drawn ADI, parallel those found in earlier experiments comparing an electromechanical ADI to the F/A-18 HUD. They suggest that a centrally located ADI in the F/A cockpit would aid pilots during unusual attitude recovery.

RPT#: AD-A183303 NADC-86157-60 86/10/00 87N29532

AUTH: A/HAINES, R. F. CORP: National Aeronautics and Space Administration. Ames Research Center. Moffett Field, Calif. CSS: (Aerospace Human Factors Research Div.) In its 20th Ann. Conf. on Manual Control, Vol. 1 p 491-514 (SEE N85-14487 05-54)

UTTL: Cockpit window edge proximity effects on judgements of horizon vertical displacement

ABS: To quantify the influence of a spatially fixed edge on vertical displacement threshold, twenty-four males (12 pilots, 12 non-pilots) were presented a series of forced choice, paired comparison trials in which a 32 deg arc wide, thin, luminous horizontal stimulus line moved smoothly downward through five angles from a

UTTL: Effects of foveal information processing

AUTH: A/HARRIS, R. L., SR.   CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va. In NASA. Dryden Flight Research Center Peripheral Vision Horizon Display (PVHD) p 81-88 (SEE N85-10044 01-06)

ABS: The scanning behavior of pilots must be understood so that cockpit displays can be assembled which will provide the most information accurately and quickly to the pilot. The results of seven years of collecting and analyzing pilot scanning data are summarized. The data indicate that pilot scanning behavior is: (1) subconscious; (2) situation dependent; and (3) can be disrupted if pilots are forced to make conscious decisions. Testing techniques and scanning analysis techniques have been developed that are sensitive to pilot workload.   84/04/00   85N10052

UTTL: Twentieth Annual Conference on Manual Control, Volume 2

AUTH: A/HART, S. G.; B/HARTZELL, E. J.   CORP: National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.   Conf. held at Moffett Field, Calif., 12-14 Jun. 1984

ANN: Volume II contains thirty two complete manuscripts and five abstracts. The topics covered include the application of event-related brain potential analysis to operational problems, the subjective evaluation of workload, mental models, training, crew interaction analysis, multiple task performance, and the measurement of workload and performance in simulation. For individual titles see N85-14536 through N85-14568.

RPT#: NASA-CP-2341-VOL-2 A-9879-VOL-2 NAS 1.55:2341-VOL-2 84/09/00   85N14535

UTTL: Dynamic holography for real-time 3-D cockpit display

AUTH: A/HOPPER, D. G.

PAA: A/(USAF, Institute of Technology, Wright-Patterson AFB, OH) IN: NAECON 1986: Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 19-23, 1986. Volume 1 (A87-16726 05-01). New York, Institute of Electrical and Electronics Engineers, 1986, p. 166-172.

ABS: The concept of dynamic holography (DH) in pilot-to-aircraft systems interface devices is examined. Holograms provide a three-dimensional capability which would enhance the ability of the pilot to perceive the spatial relationship of other aircraft in his area when presented via display. Holographic movies have already been produced with play-back fields-of-view more than sufficient for

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common starting position within a three second-long period. The five angles were 1.4, 1.7, 2, 2.3, and 2.6 deg. Each angle was presented paired with itself and the other four angles in all combinations in random order. For each pair of trials the observer had to choose which trial possessed the largest displacement. A confidence response also was made. The independent variable was the angular separation between the lower edge of a stable 'window' aperture through which the stimulus was seen to move and the lowest position attained by the stimulus. It was found that vertical displacement accuracy is inversely related to the angle separating the stimulus and the fixed window edge (p = .05). In addition, there is a strong tendency for pilot confidence to be lower than that of non-pilots for each of the three angular separations. These results are discussed in erms of selected cockpit features and as they relate to how pilots judge changes in aircraft pitch attitude.   84/09/00   85N14518

UTTL: Effect of the neutral density helmet visor on the visual acuity of navy fighter pilots

AUTH: A/HAMILTON, P. V.; B/MORRIS, A.   CORP: Naval Aerospace Medical Research Lab., Pensacola, Fla.

ABS: The visual acuity of 63 Navy fighter pilots was measured under four viewing conditions in an Automated Vision Test Battery housed in a Mobile Field Vision Test Battery housed in a Mobile Field Laboratory operated by the Naval Aerospace Medical Research Laboratory (NAMRL). These and other pilots were also interviewed concerning their visor usage habits. Use of the 12% neutral density visor resulted in an average acuity loss of about 0.51 minutes of visual angle (mva) for low contrast targets under high-luminance laboratory conditions. The visor may cause an operationally significant reduction in visual acuity in the presence of luminance levels encountered at typical flight altitudes. Pilots range widely in their sensitivities to reduced contrast and glare, so a single optical density visor would not be optimal for many pilots. Pilot attempts to identify individually-optimal strategies for using visors and sunglasses often have no objective or systematic basis. Recommendations are presented for improving the vision of aviators wearing visors.

RPT#: AD-A178486 NAMRL-1325   86/12/00   87N23147

cockpit display purposes. Such movies might provide storage of reference imagery. Dynamic holography, a technology by which holograms are read out as fast as they are written, may support the real-time portions of the display. Critical device developments required include degenerate four wave mixers (operational optical image amplifiers) and advanced real-time spatial light modulators. 86/00/00 87A16741

UTTL: Human factors associated with glass cockpit design
AUTH: A/JENNINGS, RANDLE; B/HANNERT, LARRY
PAA: A/(Honeywell, Inc., Minneapolis, MN); B/(Sperry Corp., Commercial Flight Systems Div., Phoenix, AZ)
SAE, General Aviation Aircraft Meeting and Exposition, Wichita, KS, Apr. 28-30, 1987. 12 p.
ABS: The new symbology which is replacing some of the conventional displays currently found in the cockpit is described and its evolution is traced. Comparisons are made between early 5 x 6 EFIS (electronic flight instrument system) displays and the most recent 5 x 6 display formats. Next generation features include actual environment displays, three-dimensional displays, new guidance displays, advanced sensors and their improved presentation, and new display technology.
RPT#: SAE PAPER 871036 87A48764

UTTL: Symposium on Aviation Psychology. 3rd, Columbus, OH, April 22-25, 1985, Proceedings
AUTH: A/JENSEN, R. S.; B/ADRION, J.
PAA: B/(Ohio State University, Columbus) Symposium sponsored by the Ohio State University and Association of Aviation Psychologists. Columbus, OH, Ohio State University, 1985. 777 p. For individual items see A86-29852 to A86-29861, A86-29863 to A86-29936.
ABS: The present conference on the complex interactions between pilots and their cockpit environments discusses topics in such fields as cockpit design, voice data entry for avionics, cockpit displays, air traffic control automation, pilot workload monitoring and management, pilot judgment and reliability, cockpit communications and resource management, pilot selection and training, pilot visual perception, pilot physiology, and accident investigation. Specific attention is given to cockpit design and evaluation data bases, ergonomic principles for auditory signals in military aircraft, subjective assessments of workloads in an advanced fighter cockpit, time-sharing ability in zero-input tracking analyzer scores, cockpit speech interference considerations, psychosocial aspects of male and female pilot errors,

test anxiety in cockpit simulators, fatigue, stress and preoccupation effects, and aircraft accident investigation psychological methods. 85/00/00 86A29851

UTTL: Symposium on Aviation Psychology. 2nd, Columbus. OH, April 25-28, 1983, Proceedings
AUTH: A/JENSEN, R. S.
PAA: A/(Ohio State University, Columbus, OH) Symposium sponsored by the Ohio State University. Columbus, OH, Ohio State University, 1984, 652 p. For individual items see A85-21552 to A85-21609.
ABS: Aspects of cockpit technology are discussed, taking into account color coding in fighter cockpits, the pilot-computer direct access interface provided by touch panels, performance evaluation of electronic flight instruments, a pilot's desk flight station, voice recognition technology as challenge of the 80's, synthesized voice and voice actuated control in the cockpit, and the cockpit display of traffic information and the threat alert and collision and avoidance system integration. Other topics explored are related to design reduced error, cockpit resource management, workload, judgment, pilot reliability, physiology and performance assessment, visual perception, selection, training, and simulation. Attention is given to progress in Army helicopter flight simulation, simulation as a national resource, strategy to the certification of private pilots, pilot performance evaluation involving human observer and computer, the identification of processes underlying skilled aviator performance, and an optic flow cueing model for low level flight. 84/00/00 85A21551

UTTL: Integrating the pilot into the cockpit
AUTH: A/JOHNSTON, M. B.; B/WOLFE, A. V.
PAA: B/(General Dynamics Corp., Fort Worth, TX) AIAA, AHS, CASI, DGLR, IES, ISA, ITEA, SETP, and SFTE, Flight Testing Conference, 3rd, Las Vegas, NV, Apr. 2-4, 1986. 8 p.
ABS: The designing of cockpits to fulfill mission requirements is studied. The need for pilot-vehicle interface (PVI) is discussed. The objectives of the PVI Project Lead are examined. The use of simulation in cockpit design is described. Examples displaying the progression of cockpit design complexity and workloads are presented.
RPT#: AIAA PAPER 86-9765 86/04/00 86A32102

UTTL: Advanced avionics management system prevents pilots from being swamped by information overload
AUTH: A/JOHNSTON, R.
PAA: A/(Allied Bendix Aerospace, Flight System Div., Teterboro, NJ) Defense Systems Review and Military Communications, vol. 3, no. 4, 1985, p. 11-14.
ABS: Pilots must not be so overwhelmed by flight instrument information as to experience distraction or stress. The organization of information demanded by this criterion has led to the recent development of an advanced Avionics Management System (AMS), which, although intended for a transport helicopter, is adaptable to a variety of other aircraft. This multidisplay system combines various functions that are required for control of the cockpit and the management of mission profile and aircraft performance. The displays include an Electronic Altitude Director Indicator, a Color Multifunction Display, and a keyboard. Primary and backup computers are incorporated in the AMS. 85/00/00 85A38401

UTTL: V-22 avionics methodology and design
AUTH: A/KLIPPERT, R.; B/KEY, E.
PAA: A/(IBM Corp., Owego, NY); B/(Boeing Military Aircraft Co., Wichita, KS) IN: American Helicopter Society, Annual Forum, 42nd, Washington, DC, June 2-4, 1986, Proceedings. Volume 2 (A87-19201 06-01). Alexandria, VA, American Helicopter Society, 1986, 3 p.
ABS: Attention is given to the design features and performance capabilities of the V-22's avionics system hardware and software elements. Software encompasses communication-identification, mission management, and test module monitoring; hardware prominently includes four multifunction displays driven by two display processors, two control display units, and a dual helmet-mounted display. Attention is given to the two-company development program management aspects of V-22 avionics endeavors. 86/00/00 87A19289

UTTL: Aircrew aspects of United Stated future fighter aircraft
AUTH: A/KROBUSEK, R. D. CORP: Air Force Wright Aeronautical Labs., Wright-Patterson AFB, Ohio. In AGARD Medical Selection and Physiological Training of Future Fighter Aircrew 5 p (SEE N86-30309 21-52)
ABS: The cockpit environment of fighter aircraft for the year 2000 and beyond will undoubtedly need aircraft technologies and protective devices to meet the ever growing enemy challenge. Recent advances in aircraft structures, flight controls, sensors, multipurpose and touch-sensitive displays, voice recognition and synthesis, enemy defenses, and chemical/biological warfare (CBW) technologies will combine to create a cockpit environment for future fighter aircraft vastly different and potentially more complex than any previously encountered by aircrews. This integration of equipment and crewmembers will interact such that new stresses will be created and existing ones aggravated. Special maneuver capability through the use of direct side force may provide significant tactical advantage at the expense of stress due to lateral acceleration forces. A few of these current technologies and some of the driving forces which will affect the cockpit environment of tomorrow's aircraft will be identified and discussed briefly. These technologies, as well as others, should receive further study for their effects on the aircrew prior to application in future aircraft. Proper application of the results of these studies will prevent the unbridled growth of cockpit complexity. 85/12/00 86N30310

UTTL: Binocular overlap in a fiber optic helmet mounted display
AUTH: A/KRUK, R. V.; B/LONGRIDGE, T. M. CORP: CAE Electronics Ltd., Montreal (Quebec). In AF Human Resources Lab. The IMAGE 3 Conf. Proc. p 363-378 (SEE N85-17962 09-01)
ABS: Target detection, motion detection, and flight performance were compared under conditions of 25 and 45 binocular overlap using only the low resolution background channels of a fiber optic helmet mounted display (FOHMD). In experiments 1 and 2, eight experienced fighter pilots viewed aircraft targets which either approached ownship or moved vertically in the field of view, respectively, at various angles of off axis eccentricity. As an additional task, pilots flew the system as an air combat simulator and were required to track, engage, and destroy an airborne target. The results indicated target and motion detection and binocularly displayed targets were superior to that of monocularly displayed targets. There was no significant difference in target detection or motion detection between the two overlap conditions, per se, nor between left and right fields of view. In both overlap conditions, performance was degraded within 5 of the lateral edges of the field of view, and suppression was evident in contralateral fields in the areas of optical frame overlap. However, the latter effects were combined nearer the central viewing area for the 25 deg overlap condition. No significant differences were noted in the supplementary air combat task as a function of overlap, but structured debriefing data indicated loss

of target imagery is less of a problem with the larger overlap. It is concluded that greater than 25 deg binocular overlap should be utilized in follow-on systems.
RPT#: AD-P004331   84/09/00   85N17985

UTTL: Onboard simulation - A newly emerging technology and the potential of the helmet mounted display as an embedded training device
AUTH: A/LAMBERT, R. E.; B/MEYER, R. P.; C/BRADY, B. J.; D/NORTON, S. K.
PAA: B/(McDonnell Aircraft Co., St. Louis, MO); D/(USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH)   AIAA, Flight Simulation Technologies Conference, St. Louis, MO, July 22-24, 1985. 7 p.
ABS: The enhanced Onboard Simulation effort within the U.S. Air Force's Integrated Flight/Fire Control program has been undertaken to extend air-to-air engagement mode simulations, to perform a tradeoff study which would compare the cost effectiveness of this and other forms of pilot training, and to conduct a manned simulation to determine the utility of a helmet-mounted display in onboard simulations. The Helmet-Mounted Sight/Display system employed was outfitted with a magnetic position sensor which provided helmet line-of-sight information through the 360 deg of a sphere. Attention is given to the helmet mounted display's graphics symbology and the target maneuvers undertaken by the present investigation.
RPT#: AIAA PAPER 85-1737   85/07/00   85A42664

UTTL: The wide field helmet mounted display
AUTH: A/LARUSSA, J.   CORP: Farrand Optical Co., Inc., Valhalla, N.Y.   In AGARD Guidance-Control-Navigation Automation for Night All-Weather Tactical Operations 7 p (SEE N86-26318 17-04)
ABS: The wide field helmet mounted display developed by the Farrand Optical Company, Inc. is described. This display provides the pilot with an instantaneous field of view of 60 deg vertically and 135 deg horizontally. The central field of view consists of an overlap field of 25 deg within which full stereopsis is available. It would appear that a new design which the Farrand Optical Company, Inc. is now in the process of designing for Aerospace Medical Research Laboratory (AMRK) would be applicable for night all weather operations where such data as flight path control, computed weapon projectories, synthetic outside world views, expected and unexpected threats and automatic terrain following paths would be displayed. The parameters that must be considered in designing a wide field helmet mounted display are discussed. Briefly,

these parameters are size, weight and balance on the head, brightness of the display and see-through ability of the display. The discussion assumes the use of a one inch, high brightness, high resolution CRT input already developed and operational.   85/10/00   86N26322

UTTL: Method of calculating angular dimensions of flight vehicle cockpit canopy casings
AUTH: A/LEKAREV, A. V.   CORP: Joint Publications Research Service, Arlington, Va.   In its USSR Report: Space Biology and Aerospace Medicine, Vol. 19, No. 4, Jul. - Aug. 1985   (JPRS-USB-85-006) p 120-124 (SEE N86-15865 06-51)
ABS: The view from flight vehicle (FV) cockpits is an important factor in assuring flying safety and providing comfortable conditions for the pilot's visual observation of space outside the cockpit. At the present time, transparent parts of most cockpits in different types of FV are executed in the form of flat panels installed into the metal frame of the cockpit canopy. Presence of opaque components (casings) in the cockpit canopy results in obscuring part of the outside area, which worsens viewing conditions from the pilot's work place. In order to improve the view from FV cockpits with flat transparent parts, a method was developed for calculating the angular dimensions of casings (seams) on the basis of distinctions of human binocular vision. The proposed method makes it possible to meet the requirements as to strength features of the canopy frame and provide for comfortable viewing conditions outside the cockpit. The method is based on crossed diplopia in an empirical horopter from a point of the cyclopic eye of the observer.   85/11/04   86N15886

UTTL: The automated cockpit improves hands-off performance
AUTH: A/LERNER, E. J.   Aerospace America (ISSN 0740-722X), vol. 22, Nov. 1984, p. 80-83.
ABS: The 757/767 airliner's automated computer system is the control center for an interlocked computer system that manages all aspects of flight. This all-digital design is held by its creators to be able to yield fuel savings of 2-5 percent, while reducing crew size, lowering maintenance costs, and prolonging MTBF. The Flight Management System computer network functions encompass flight control, engine indicator, sensor, and display subsystems. The most vital electronic components of the system, which are the Flight Control Computer, internal reference system, altimeter, and Instrument Landing System, are triply redundant.

the pilot's maneuver of choice, and that additional studies are needed concerning the time a pilot must spend to utilize the CDTI and the effectiveness of the CDTI/TCAS system in areas with high air traffic densities.   84/00/00   85A21559

UTTL: A quantitative measure of monochrome CRT displays
AUTH: A/LIBERIO, T. A.
PAA: A/(USAF, Aeronautical Systems Div., Wright-Patterson AFB, OH)   IN: NAECON 1984: Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 21-25, 1984. Volume 2 (A85-44976 21-01). New York, IEEE, 1984, p. 911-914.
ABS: Efforts to develop a technically reliable means of evaluating monochrome CRT displays for aircraft cockpits are reviewed. Consideration is given to the development of design criteria for CRT displays based on the physical aspects of vision. These design parameters include spectral output; luminance; resolution; and contrast ratio. Some basic test equipment used in measuring CRT parameters are described, including spectroradiometer systems; slit aperture photometers; and video pattern/symbol generators.   84/00/00   85A45103

UTTL: Evaluation of formats for aircraft control/display units
AUTH: A/MANN, T. L.; B/LEIKER, L. A.
PAA: B/(Lockheed-Georgia Co., Marietta)   IN: Symposium on Aviation Psychology, 3rd, Columbus, OH, April 22-25, 1985. Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985, p. 135-142.
ABS: In this preliminary study of the definition of an optimal control/display unit display format design which will ensure effective and efficient human performance in the cockpit environment, subjects visually searched alphanumeric displays for a single unit of information and indicated when it was found. Data was thus collected on the accuracy of information retrieval, as well as the elapsed time to isolate the information; ten formats of two information densities each were evaluated, each of which contained labels and associated data for typical flight data and communications data. The results obtained indicate that both format design and density affect operator response time and accuracy. Implications of these findings are discussed.   85/00/00   86A29864

Attention is presently given to the cockpit Display of Traffic Information system, which shows the pilot, on a map-like CRT display, the positions and courses of other aircraft in the vicinity.   84/11/00   85A14017

UTTL: Helping the pilot handle the supercockpit
AUTH: A/LERNER, ERIC J.   Aerospace America (ISSN 0740-722X), vol. 25, Feb. 1987, p. 28-31.
ABS: Human factors are a focus in design studies for advanced cockpits, where pilots will have instantaneous access to sensor data. Workload control methods are being examined by monitoring physiological responses to piloting tasks. Heart rate, blinking and EEG frequencies increase with workload. An EEG wave pattern (p-300) has been correlated with the moment of decision. Its decrease in amplitude with the duration of high workload signals impaired decision-making. Microencephalographic sensors are being developed for in-flight p-300 wave monitoring of military pilots. Other research includes the development of blackout sensors, an electronic 'pilot's associate' to aid pilots after blackouts, and a Virtual Panorama Display which would analyze the pilot workload for a given image. Sound stimuli and their mode of presentation are being examined to replace some visual data displays. In the most farseeing studies, consideration is being given to tuning supercockpits directly to pilot brainwaves.   87/02/00   87A31210

UTTL: The Cockpit Display of Traffic Information and the Threat Alert and Collision Avoidance System Integration - A review
AUTH: A/LESTER, P. T.; B/QUAN, E. E., JR.
PAA: A/(San Jose State University, San Jose, CA); B/(California, University, Berkeley, CA)   IN: Symposium on Aviation Psychology, 2nd, Columbus, OH, April 25-28, 1983. Proceedings (A85-21551 08-53). Columbus, OH, Ohio State University, 1984, p. 69-75.
ABS: The Cockpit Display of Traffic Information (CDTI) and the Threat Alert and Collision Avoidance System (TCAS) integration will display traffic in the vicinity of an aircraft and issue maneuver commands to pilots to aid in the prevention of aircraft collisions. Discussed were the effects of adding more displays to an increasingly automated cockpit and the consequences of changing the design of aircraft from three to two man crews when using the CDTI/TCAS system. Studies were analyzed to find efficient display symbology for the CDTI, the problem of false alarms and their effect on pilot confidence in the CDTI/TCAS system, and the problem of pilot disagreement with TCAS commands. The authors suggest that the TCAS commands be closer to

UTTL: Human factors: The Cinderella discipline in cockpit interface design
AUTH: A/MARTIN, K. W.; B/LAYCOCK, J.
PAA: B/(Royal Aircraft Establishment, Farnborough, England)
CORP: British Aerospace Public Ltd. Co., Lancashire (England). CSS: (Cockpit Specialist Group.) In AGARD Visual Protection and Enhancement 10 p (SEE N86-26802 17-52)

ABS: The present trend in military aircraft design towards compact cockpits, multifunction controls and displays, and integrated systems within more agile and smaller airframes, has resulted in a greater need for human factors involvement in the design of the man machine interface. The cockpit of the modern military aircraft is inevitably a compromise of conflicting design disciplines, and one in which human factors fails to achieve any long term influence because the discipline lacks the absolute argument necessary for survival in the industrial environment. If human factors are to establish the degree of influence the current levels of research justify, then a new approach is necessary. This approach must recognize the practical problems associated with the design and manufacture of the integrated weapons delivery system that future aircraft represent. One possible approach may be the generation of human factors design tools, for use by engineers, which incorporate human sensory emulations and provide outputs that can be integrated into the engineering discipline. 85/12/00 86N26825

UTTL: The effect of modified spectacles on the field of view of the helmet display unit of the integrated helmet and display sighting system
AUTH: A/MCLEAN, W. E.; B/RASH, C. E. CORP: Army Aeromedical Research Lab., Fort Rucker, Ala.

ABS: A study was conducted to establish the effect of wearing modified aviator spectacles, either for laser protection or refractive error correction, on the field-of-view available with the Helmet Display Unit (HDU) of the Integrated Helmet and Display Sighting System (IHADSS). The determining factors of the available field were found to be helmet fit, eye fixation direction, and eye relief distance. The study concluded that when these factors are optimized, the wearing of the modified spectacles does not result in a loss of field-of-view. 84/09/00 85N18055
RPT#: AD-A148693 USAARL-84-12

UTTL: Sophisticated integral control methods for use in flight
AUTH: A/MENU, J.-P.; B/SANTUCCI, G.; C/AMALBERTI, R. CORP: Centre d'Etudes et de Recherches de Medecine Aerospatiale, Paris (France). In AGARD, Information Management and Decision Making in Advanced Airborne Weapon Systems 6 p (SEE N87-29503 24-06)

ABS: The changing nature of display and control requirements for modern aircraft and the various means by which information is transferred to and from the pilot are reviewed. Some of the known factors affecting human performance are discussed including: (1) desaturation and contrast loss in electronically generated information during high illumination inflight conditions; (2) the effects of high acceleration on both foveal and peripheral presentations of information; (3) manual control designs which obscure some settings when engaged; and (4) the improper labelling of display and control devices. The potential use of voice interactive control devices, especially in overcoming problems inherent in multitask situations, is also discussed. Finally, the relative merits of dedicated and multifunctional displays and controls are examined along with the theoretical causes of increased higher cognitive workloads required by multifunction devices. 87/02/00 87N29510

UTTL: Organization of displays in the visual space of the combat aircraft pilot
AUTH: A/MENU, J.-P.; B/AMALBERTI, R. CORP: Centre d'Etudes et de Recherches de Medecine Aerospatiale, Paris (France). CSS: (Lab. Central de Biologie Aerospatiale.) In AGARD, Information Management and Decision Making in Advanced Airborne Weapon Systems 12 p(SEE N87-29503 24-06)

ABS: The psychophysiological problems associated with the specific organization of cockpit displays were examined through laboratory studies and pilot surveys. The response time associated with the transition between head-up and head-down displays was measured under various conditions. It was found that reduced transition times could be obtained through the use of intermediate display concepts. Illumination level and visual adaptation were identified as important factors in the optimal integration of displays. 87/02/00 87N29516

UTTL: Head-up/head-down transition - Measurement of transition times
AUTH: A/MENU, J.-P. R.
PAA: A/(Centre d'Etudes et de Recherches de Medecine Aerospatiale, Paris, France) Aviation, Space, and Environmental Medicine (ISSN 0095-6562), vol. 57, March 1986, p. 218-222. DRET-supported research.
ABS: A method to measure transition times between a head-up display (HUD) signal and a response given to a head-down display (HDD) was developed, using a three-segmented paradigm and testing various vocal and manual arrangements in a fighter aircraft mock-up. The shortest transition times were obtained for voice responses (1600 msec between a HUD signal and a simple response to the HDD). A comparison of the perception and transition times of a 'positive' contrast (green symbols on black background) with a 'negative' contrast (black symbols on green) has indicated both shorter perception and shorter transition times for the positive contrast. This method permits of the effects evaluation of changes in psychological conditions (such as heavier information processing) and physiological conditions (changing accommodation, gaze axis, and convergence) of a dynamic aeronautical environment on the speeds of acquisition and processing of information. 86/03/00 86A29092

UTTL: The F-18: A new era for human factors
AUTH: A/MERRIMAN, S. C.; B/MOORE, J. P.
PAA: B/(McDonnell Douglas Corp., St. Louis) CORP: Naval Air Development Center, Warminster, Pa. In AGARD Human Factors Considerations in High Performance Aircraft 5 p (SEE N85-19653 10-54)
ABS: The crew station of the Navy/Marine Corps' newest high performance tactical jet aircraft - the F/A-18 HORNET and the human factors effort involved in its development and testing are described. The F/A-18 represents the first of a new generation of military aircraft. Its development posed a host of novel man machine interface, crew station design and human factors engineering problems in need of creative solutions. Compared to other tactical jet aircraft currently serving the military, the F/A-18 is, by design, the most mission flexible and growth accommodating aircraft in the inventory. To develop the HORNET major changes in the human factors engineering approach were required. Involved are: thorough mission analyses, technology risk assessment and a step-by-step process of proof or concept in realistic mission simulators. 84/11/00 85N19671

UTTL: Application of magneto-optic modulators to advanced avionic displays
AUTH: A/MOFFAT, A. J.; B/QUAGLIA, A.; C/BAJCAR, R. C.
PAA: C/(Litton Systems Canada, Ltd.; Rexdale, Canada) IN: NAECON 1985: Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 20-24, 1985. Volume 2 (A86-28326 12-04). New York, Institute of Electrical and Electronics Engineers, 1985, p. 1511-1518.
ABS: The magnetooptic light modulator (based on the Faraday effect) is examined as a means of significantly improving avionics displays for future aircraft. The light modulator has application to high brightness raster-scan projector systems suitable for use in head-up displays, head-down displays, and helmet mounted displays. The basic principles of the device and its characteristics are explained. 85/00/00 86A28506

UTTL: Pilot/Vehicle Interface Design System (PIVIDS)
AUTH: A/MOORE, R. D.; B/MOORE, C. A.
PAA: B/(Verac, Inc.; San Diego, CA) IN: NAECON 1985: Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 20-24, 1985. Volume 2 (A86-28326 12-04). New York, Institute of Electrical and Electronics Engineers, 1985, p. 1556-1563.
ABS: A concept for a rapid prototyping simulator for the cockpit display problem has been developed. Called the Pilot Vehicle Interface Design System, or PIVIDS, the system is a response to the problem of evaluating the pilot/vehicle interface with regard to complex, new multifunction displays. The F-16C/D cockpit, which has ten computers (communicating with each other over three multiplex buses) and a variety of display units is considered as an example where PIVIDS can greatly aid the designer. The system is suited to a broad range of other applications. 85/00/00 86A28512

UTTL: Laser eye protection visor using multiple holograms.
AUTH: A/MOSS, G. E. CORP: Department of the Navy. Washington, D. C.
ABS: This patent discloses a diffractive radiation shield for protecting eyes and radiation sensitive devices from laser radiation. The shield utilizes one or more holograms disposed on transparent substrates. These holograms consist of spherical holographic fringes recorded in a dichromated gel with which the substrates are coated. The holographic fringe reflect laser radiation which is normal to their respective surfaces. Reflectivity is maximized for a particular wavelength by proper selection of the fringe spacing.

The shield may be configured as a visor for an aviator's helmet.
RPT#: AD-D012455 US-PATENT-4,601,533
US-PATENT-APPL-SN-437729 US-PATENT-CLASS-350-3.7
86/07/22 87N13995

UTTL: Visual display research tool
AUTH: A/MURRAY, P. M.; B/BARBER, B. CORP: Rediffusion
Simulation Ltd., Crawley (England). In AGARD Flight
Simulation 8 p (SEE N87-23633 17-09).
ABS: The Visual Display Research Tool (VDRT) is a new
concept in visual displays which utilizes area of
interest approach by matching its display parameters
to those of the human eye. Two fields of view are
employed, a wide-angle field corresponding to the
peripheral area and an area of interest field inset at
its center. The combined field is coupled to head and
eye movements such that the direction of gaze is
followed and a detailed scene is apparent over the
whole field of regard at all times. The specific
design chosen for VDRT is based on helmet mounted
projection of two full color rasters onto the interior
surface of a spherical dome surrounding the cockpit.
The VDRT has been designed to meet the specified
performance in a manner which allows a great deal of
flexibility in system performance under software
control. It should enable a lot of experimental
results to be obtained on the performance and
suitability of a head mounted eye tracker area of
interest system as a training device. 86/09/00
87N23635

UTTL: Design considerations for an eye tracked AOI
(Area of Interest) display system
AUTH: A/NEVES, F. B. CORP: General Electric Co., Daytona
Beach, Fla. In AF Human Resources Lab. The IMAGE 3
Conf. Proc. p 255-266 (SEE N85-17962 09-01)
ABS: The potential benefits of using an Area of Interest
(AOI) display for high performance out-the-window
visual simulation is evidenced by the current activity
in this display technology. The AOI concept can be
implemented in many versions. In each AOI display type
a complex tradeoff of performance parameters must be
considered. A review of these considerations will be
discussed in this paper concentrating upon the display
versus the CIG. The display being developed for the
Visual System Component Development Program (VSCDP) by
the General Electric Company (GE) is an AOI display
concept. The major features of the display system and
the current status of the display development will be
discussed.
RPT#: AD-P004324 84/09/00 85N17978

UTTL: Current and future general aviation EFIS
developments
AUTH: A/OGANN, J. A.
PAA: A/(Rockwell International Corp., Collins General
Aviation Div., Cedar Rapids, IA) IN: Digital
Avionics Systems Conference, 6th, Baltimore, MD,
December 3-6, 1984, Proceedings (A85-17801 06-01). New
York, American Institute of Aeronautics and
Astronautics, 1984, p. 193-198.
ABS: Electronic flight instrumentation systems (EFIS) under
development or in use on general aviation aircraft are
surveyed. EFIS became possible when high reliability
CRT displays were produced for the cockpit. The key
factor was the manufacture of vibration-proof shadow
mask tubes, certifiable high voltage systems, high
speed processors and A/D converters and high level
language implementation. Display formats have been
defined for airspeed, airspeed trend, Mach number,
take-off acceleration, flight mode, ground speed, and
radio altitude. Full altimetry is still under study.
Efforts have been expended to produce displays that
mimic mechanical gages to interface with pilot
familiarities. Color standards are being established
for various information categories, and decisions are
being made of acceptable multifunction displays. It is
noted that cockpit display technology is still in its
infancy and that major changes are to be expected in
all display components and functions.
RPT#: AIAA PAPER 84-2642 84/00/00 85A17831

UTTL: Wide angle distortion free holographic head-up
display.
AUTH: A/PERRIN, J. C.
PAA: A/(Telecommunications Radioelectriques et
Telephoniques, Le Plessis-Robinson, France) IN:
Progress in holographic applications; Proceedings of
the Meeting, Cannes, France, December 5, 6, 1985
(A87-19820 07-35). Bellingham, WA, Society of
Photo-Optical Instrumentation Engineers, 1986, p.
178-183.
ABS: A new optical design of a 60 deg x 30 deg holographic
display is demonstrated. The arrangement uses two
holograms, a relay lens, and a Schmidt plate. The
first hologram is used as collimator and combiner and
gives complete see through capability. The second
hologram is a field hologram. Ray traces and spot
diagrams, which have been obtained with a computer
program especially developed for this analysis, are
shown. 86/00/00 87A19823

UTTL: Interactive design tool for cockpit controls and displays development
AUTH: A/QUALLS, G.
PAA: A/(Boeing Military Airplane Co., Wichita, KS) AIAA, AHS, and ASEE, Aircraft Systems, Design and Technology Meeting, Dayton, OH, Oct. 20-22, 1986. 7 p.
ABS: The architecture of the Virtual Avionics Driver System (VADS) utilized for the development of interactive controls and displays for a crew station is described. The system consists of a portable, user programmable terminal. The VADS employs a user definable cockpit control language and state tables containing data on the functionality of operator actions. The functions of the switch, task, and data tables are discussed. The hardware of the system performs state table sequencing, command processing, and input/output.
RPT#: AIAA PAPER 86-2735   86/10/00   87A17953

UTTL: Color coding in fighter cockpits - It isn't black and white
AUTH: A/REISING, J. M.; B/ARETZ, A. J.
PAA: B/(USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, OH) IN: Symposium on Aviation Psychology, 2nd. Columbus, OH, April 25-28, 1983, Proceedings (A85-21551 08-53). Columbus, OH, Ohio State University, 1984. p. 1-7.
ABS: The use of color in display formats is a topic which is causing a great deal of interest. One of the results of research in this area is that, for display formats of medium complexity, there is often no performance improvement with color displays - even though the operators overwhelmingly prefer color. Reducing subject viewing times and utilizing multivariate statistics are two approaches which may be able to differentiate the subtle performance variations between color and monochrome display formats of medium complexity.   84/00/00   85A21552

UTTL: The cockpit of the year 2000: How big a step?
AUTH: A/REISING, J. M.; B/EMERSON, T. J. CORP: Air Force Flight Dynamics Lab., Wright-Patterson AFB, Ohio. In AGARD Human Factors Considerations in High Performance Aircraft 4 p (SEE N85-19653 10-54)
ABS: The cockpit of the year 2000 is envisioned to be dramatically different from those of current fighter aircraft. The upcoming hardware and software available in the mid 1990s are discussed together with the impact on the pilot of having them available for use. Among the advanced technologies considered are electro-optic displays, voice control, touch sensitive overlays, programmable switches, helmet mounted displays, and artificial intelligence software.   84/11/00   85N19667

UTTL: Cockpit information requirements analysis - A mission orientation
AUTH: A/RILEY, D. D.; B/BREITMAIER, W. A.
PAA: A/(Essex Corp., Warminster, PA); B/(U.S. Navy, Naval Air Development Center, Warminster, PA) IN: Symposium on Aviation Psychology, 3rd, Columbus, OH, April 22-25, 1985, Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985, p. 55-61.
ABS: A methodology has been developed to derive, on the basis of mission needs, the cockpit information requirements of A-6F and V-22 naval aircraft. After determining a representative mission scenario, the mission is broken down into segments and subjected to a function analysis. Functions are then allocated to either human operator or machine control, and cockpit task requirements for each mission segment are derived together with the cockpit information presentation capabilities necessary for operator performance of each task item. Operator task responsibilities are then assigned according to crew position or function for each mission segment.   85/00/00   86A29856

UTTL: There's a voice in the sky - But can a picture tell you more?
AUTH: A/ROBINSON, C. P.; B/EBERTS, R. E.
PAA: A/(USAF, Aeronautical Systems Div., Wright-Patterson AFB, OH); B/(Purdue University, West Lafayette, IN) IN: Human Factors Society, Annual Meeting, 29th, Baltimore, MD, September 29-October 3, 1985, Proceedings. Volume 1 (A86-33776 15-53). Santa Monica, CA, Human Factors Society, 1985, p. 61-65.
ABS: A current trend in cockpit design is to incorporate synthesized speech to present secondary information. Multiple resource theories of information processing support this, but theories of stimulus-central processing-response compatibility suggest that spatial information presented visually may have some advantages over speech. An experiment was run comparing tracking and response performance when information was presented pictorially and by speech. Pictorial subjects responded quicker and improved more with learning than did speech subjects. More research on the spatial advantages of pictorial displays is needed before too many speech displays are incorporated into the cockpit.   85/00/00   86A33781

UTTL: A comparison of pictorial and speech warning messages in the modern cockpit

AUTH: A/ROBINSON, C. P. CORP: Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.

ABS: This thesis presents a current trend in cockpit design to incorporate synthesized speech to present secondary information to the pilot in an attempt to reduce mental workload, and to allow the pilot to keep his or her view out of the cockpit. Theories of multiple resource information processing support both of these reasons to use synthesized speech, but the theories of stimulus-central processing-response (S-C-R) compatibility suggest the possibility that spatial information presented visually may have some distinct advantages over speech even though it uses the same input modality as the primary (flying) task. If the response is to be manual, then spatial information is more compatible. Twenty subjects participated in three dual-task experiments which compared tracking and emergency response performance when information was presented in the visual/spatial (pictorial) mode as opposed to the auditory/verbal (speech) mode. In all three experiments the pictorial mode elicited quicker response times, though in one experiment the pictorial mode also elicited more errors. Also, the pictorial subjects improved more with learning than did the speech subjects. While the subjects were not successful at protecting their primary task when they added the secondary task, there were no interactions between the task type and any other factor. These results indicate that more research concerning the spatial advantages of pictorial displays needs to be conducted before too many speech displays are incorporated into the cockpit.

RPT#: AD-A151317 AFIT/CI/NR-85-23T 84/12/00 85N26706

UTTL: Comparison of speech and pictorial displays in a cockpit environment

AUTH: A/ROBINSON, CHRISTOPHER P.; B/EBERTS, RAY E.

PAA: A/(USAF, Aeronautical Systems Div., Wright-Patterson AFB, OH); B/(Purdue University, West Lafayette, IN) Human Factors (ISSN 0018-7208), vol. 29, Feb. 1987, p. 31-44.

ABS: A current trend in cockpit design is to incorporate synthesized speech to present secondary information. Multiple-resource theories of information processing support this, but theories of stimulus/central-processing/response compatibility suggest that spatial information presented visually may have some advantages over speech if the response is manual. Two experiments compare response performance over single and dual tasks when information was presented pictorially and by speech. Pictorial subjects responded more quickly than did speech subjects. The addition of the visual tracking task in the dual-task condition had a differential effect on performance, depending on the modality of the primary task and the rate at which information was presented. The dual task impeded performance more in the fast and medium presentation rates for the speech condition but had little differential effect across rates for the pictorial condition. Analysis of the error data indicated that subjects in the pictorial condition were better able to maintain the context of the emergency than those in the speech condition. Results are discussed in terms of current theories of information processing. 87/02/00 87A43773

UTTL: Luminance contrast requirements for legibility of symbols on computer-generated map displays in aircraft cockpits

AUTH: A/ROGERS, S. P.; B/SPIKER, A.; C/CICINELLI, J.

PAA: C/(Anacapa Sciences, Inc., Santa Barbara, CA) IN: Symposium on Aviation Psychology, 3rd, Columbus, OH, April 22-25, 1985, Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985, p. 175-182.

ABS: Difficulties regarding the translation of research findings into design recommendations in the case of symbol luminance have been related to inconsistent results. The present paper is concerned with studies which have been conducted with the aim to avoid the shortcomings of earlier investigations. In the described experiments, luminance and luminance contrast effects in low, moderate, and high ambient illumination environments are examined. The obtained results confirm and extend previous findings in the visual adaptation area. Average response time decreased with increases in contrast ratio, decreases in adaptation luminance, and increases in display background luminance. The result of the current investigation underlines the importance of basing cockpit display design decisions on quantitative perceptual d a. 85/00/00 86A29869

UTTL: Cognitive network organization and cockpit automation

AUTH: A/ROSKE-HOFSTRAND, R. J.; B/PAAP, K. R.

PAA: A/(NASA, Ames Research Center, Moffett Field, CA; New Mexico State University, Las Cruces); B/(IBM Santa Teresa Laboratories, San Jose, CA; New Mexico State University, Las Cruces) CORP: National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.; New Mexico State Univ., Las Cruces.; IBM Research Lab., San Jose, Calif. IN: Symposium on Aviation Psychology, 3rd, Columbus, OH.

ABS: April 22-25, 1985. Proceedings (A86-29851 13-53). Columbus, OH, Ohio State University, 1985, p. 71-78. Attention is given to a technique for the derivation of pilot cognitive networks from empirical data, which has been successfully used to guide the redesign of the Control Display Unit that serves as the primary interface of the complex flight management system being developed by NASA's Advanced Concepts Flight Simulator program. The 'pathfinder' algorithm of Schvaneveldt et al. (1985) is used to obtain the conceptual organization of four pilots by generating a family of link-weighted networks from a set of psychological distance data derived through similarity ratings. The degree of conceptual agreement between pilots is assessed, and the means of translating a cognitive network into a menu structure are noted. 85/00/00 86A29858

UTTL: HMD: Global HUD solution
AUTH: A/ROTIER, D. J.
PAA: A/(Honeywell, Inc., Avionics Div., St. Louis Park, MN) IN: Specialists' Meeting on Advanced Cockpit Design, Grapevine, TX, October 3, 4, 1984, Proceedings (A86-18451 06-06). Alexandria, VA, American Helicopter Society, 1984, 14 p.
ABS: A comparative assessment is made of candidate Helmet Mounted Display (HMD) system configurations for single crew member helicopter night flying, giving attention to aircraft loss probability in a high threat combat environment due to system failures, and to the achievement of a minimum head-supported weight value for a system that furnishes the requisite display system redundancy. Both monocular/binocular HMD systems are considered, as are combined monocular/binocular, image intensifier-based, and night vision goggles-based systems. Redundant sensors are noted to be required for combat safety and mission effectiveness. 84/00/00 86A18460

UTTL: Computer aided crewstation information allocation
AUTH: A/ROWLAND, M. E.; B/WAGONER, W. R.
PAA: A/(Boeing Military Airplane Co., Wichita, KS) AIAA, AHS, and ASEE, Aircraft Systems, Design and Technology Meeting, Dayton, OH, Oct. 20-22, 1986. 7 p.
ABS: The challenge of designing an effective operator oriented crewstation is being met with a new computer enhanced methodology. Using mission requirements as a spring board, this methodology synthesizes hardware, software, and Human Factors criteria, insuring that all needed mission capabilities are merged into a total Controls and Displays concept. The process was accomplished by developing a computer program which optimizes information allocation to display type and location and control type and location according to several critical parameters assigned by the designer. The result is a crewstation design which logically integrates the multiple outputs of sophisticated avionics in a way that allows high operator efficiency. Initial validation results indicate that the methodology provides a logical flow-down of information requirements into an integrated crewstation design.
RPT#: AIAA PAPER 86-2734 86/10/00 87A17952

UTTL: Advanced visual stimulation device using miniature TV receiver
AUTH: A/SAITO, I.; B/MIZUMOTO, K.; C/ONO, M.
PAA: A/(Research Foundation on Traffic Medicine, Tokyo, Japan); C/(Japan Air Self Defence Force, Tokyo, Japan) (International Astronautical Federation, International Astronautical Congress, 34th, Budapest, Hungary, Oct. 9-15, 1983) Japanese Journal of Aerospace and Environmental Medicine (ISSN 0387-0723), vol. 21, June 1984, p. 11-17. In Japanese, with abstract in English.
ABS: Four male subjects equipped with helmets supporting miniature television receivers placed in front of either eye were exposed to patterns while seated in a spatial orientation flight training simulator. The simulator was capable of rotating at 15 rpm in either direction and included a dark canopy which prevented the subjects from receiving external stimuli. Three types of patterns were projected: static lines and stripes moving L-R or R-L at a rate corresponding to motion at 15 rpm. All possible combinations of movement were examined and eye motions were monitored. Conflict between bodily and visual motion direction stimuli failed to lead to dizziness, disorientation and nausea observed by other experimenters, although variations in both phase and amplitude of the nystagmus were elicited. The data are concluded insufficient for confirming that optokinetic effects can stimulate motion sickness. 84/06/00 85A27977

UTTL: Advances in display technology V; Proceedings of the Meeting, Los Angeles, CA, January 24, 25, 1985
AUTH: A/SCHLAM, E.
PAA: A/(U.S. Army, Electronic Technology and Devices Laboratory, Fort Monmouth, NJ) Meeting sponsored by SPIE - The International Society for Optical Engineering. Bellingham, WA, SPIE - The International Society for Optical Engineering (SPIE Proceedings. Volume 526), 1985, 124 p. For individual items see

ABS: A86-32315 to A86-32323.
Display human factors, and various advanced display systems, including CRT and projection display systems, electroluminescent displays, and passive displays, are discussed. Papers are presented on the selection of the best visual system, the effects of adaptation and display luminance on CRT symbol recognition time, and minimum color differences required to recognize small objects on a color CRT. Consideration is given to such display systems as a 160 megapixels per second 2000 line display, a full color liquid crystal light valve projector, and a thin film electroluminescent display optimized for cockpit application. Papers on passive displays include those on amorphous silicon thin film transistor-driven liquid crystal displays, a display based on switchable zero-order diffraction grating valves, and a liquid crystal display system for mass audience viewing.
RPT#: SPIE-526 85/00/00 86A32314

UTTL: Changing system and display concepts and their impact on aircrew performance
AUTH: A/SCHMIT, V. P. CORP: Royal Aircraft Establishment, Farnborough (England). CSS: (Flight Systems Dept.)
In AGARD Human Factors Considerations in High Performance Aircraft 11 p (SEE N85-19653 10-54)
ABS: Future aircraft equipment fits and flight profiles are threatening to overload the operator's ability to accept and process the information presented to him, as direct results of an increase in information volume and a reduction in time available. It is assumed that, for the foreseeable future, the primary modality for information display in the cockpit should remain visual, while control inputs to the system will be mutable in modality. A number of topics relating to visually displayed information are considered: (1) design of spatial location cueing symbology; (2) design of spatial location cueing symbology; (3) selective attention and display coding conventions; (4) design procedures for new tactical symbology; (5) information integration in flight information displays; and (6) the costs of attention switching in the flying task. Some new tactical information display concepts are discussed, and areas of research necessary to support future aircraft displays and systems are highlighted.
84/11/00 85N19665

UTTL: Review of industrial applications of HOEs in display systems
AUTH: A/SCHWEICHER, E. J. P.
PAA: A/(Armee de Terre, Centre de Recherches, Vilvoorde, Belgium) IN: Progress in holographic applications; Proceedings of the Meeting, Cannes, France, December 5, 6, 1985 (A87-19820 07-35). Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1986. p. 66-80.
ABS: The characteristic properties of holographic mirrors and various applications for holographic optical elements (HOEs) are discussed. The relationship between Bragg's law and diffraction efficiency is studied. The development of HOEs using dichromated gelatin is described; consideration is given to the spectral and angular selectivities of the HOEs. The uses of the HOEs for helmet-mounted displays, holographic night vision goggles, and holographic or diffractive optics head-up displays are examined.
86/00/00 87A19821

UTTL: Stored terrain data base aided pilotage for helicopters
AUTH: A/SEILER, N. C.; B/GRACIA, J. A.
PAA: B/(Harris Corp.) Harris Government Aerospace Systems Div., Melbourne, FL) IN: American Helicopter Society, Annual Forum, 41st, Fort Worth, TX, May 15-17, 1985. Proceedings (A86-35601 16-01). Alexandria, VA, American Helicopter Society, 1985. p. 101-109.
ABS: A panoramic pilotage display, enhanced by a topographical data base, can significantly improve military helicopter pilot efficiency while reducing workloads. The basic task of geographic orientation is automated through the provision of a planview map with tactical symbology on a head-down display. The stored data base required allows for a look-ahead capability from topographical cover positions; this is especially useful when presented in a perspective format on the head-down display. A system of this type is applicable to the U.S. Army's next-generation 'LHX' single-crewmember combat helicopter. 85/00/00 86A35606

UTTL: Optical tolerances for alignment and image differences for binocular helmet-mounted displays
AUTH: A/SELF, HERSCHEL C. CORP: Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio.
ABS: The literature on optical alignment and image difference tolerances for binocular devices are reviewed. Tolerances for vertical and horizontal misalignment and for rotation, magnification and

luminance differences are recommended. Recommendations are made for collimation tolerance and for eye relief and exit pupil diameter for helmet-mounted binocular displays. Formulas are derived for magnification difference tolerances for partially and totally overlapping fields of view.

RPT#: AD-A174536 AAMRL-TR-86-019 86/05/00 87N16521

UTTL: Don't fowl out
AUTH: A/SHULTZ, H. A. CORP: Naval Facilities Engineering Command, Philadelphia, Pa. CSS: (Applied Biology Program.) In PEER Consultants, Inc. Wildlife Hazards to Aircraft Conf. and Training Workshop p 13-23 (SEE N85-19938 11-03)
ABS: Bird strike hazard reports prepared after collisions between birds and Naval aircraft indicate that there are many measures available to pilots which can reduce the risk of future collisions. These include: scheduling flights around peaks of bird activity, avoiding bird habitats, restricting speed at low altitudes, lookout vigilence, visor discipline, aircraft to aircraft and aircraft to control tower communication, preflight briefings, bird strike avoidance training, development of a Bird Aircraft Strike Reduction Plan for each air facility, and good reporting.
RPT#: AD-P004179 84/05/00 85N19941

UTTL: A systematic program for the development and evaluation of airborne color display systems
AUTH: A/SILVERSTEIN, L. D.; B/MERRIFIELD, R. M.; C/SMITH, W. D.; D/HOERNER, F. C.
PAA: A/(General Physics Corp., Atlanta, GA); C/(Boeing Commercial Airplane Co., Seattle, WA); D/(U.S. Naval Air Test Center, Patuxent River, MD) IN: Advanced Aircrew Display Symposium, 6th, Patuxent River, MD, May 15, 16, 1984, Proceedings (A85-38951 18-06), Patuxent River, MD, U.S. Naval Air Test Center, 1984, p. 3-44.
ABS: The recent proliferation of new color display applications is partly related to a growing interest in the potential advantages of a color information display for enhancing human performance in complex man-machine systems. Another contributing factor is the availability of a rapidly evolving display technology to support advanced color display concepts. An obvious application of color display technology is connected with airborne operations. It is pointed out that piloting and airborne command/control tasks involve complex, highly-dense forms of information, entail periodic episodes of high operator workload, and are often performed under suboptimal environmental conditions. A systematic program for the development and evaluation of airborne color display systems has recently been initiated. In the present paper, attention is given to the overall architecture of the program, details regarding the objectives and approach for current program activities, and a few select issues of interest for color display system design.
84/00/00 85A38952

UTTL: Electronic displays: Their strengths and weaknesses for advanced high performance aircraft
AUTH: A/SNYDER, H. L.; B/BOGLE, R. H. CORP: Virginia Polytechnic Inst. and State Univ., Blacksburg. CSS: (Dept. of Industrial Engineering and Operations Research.) In AGARD Human Factors Considerations in High Performance Aircraft 11 p (SEE N85-19653 10-54)
ABS: Various aircraft cockpit display technologies are compared on the basis of maximum size, maximum spatial resolution, available colors, luminance, and luminance range. The specific technologies considered are CRT, plasma discharge, electroluminescent, liquid crystal, electrochromic, and light emitting diode. The technological parameters of the cockpit displays are discussed with respect to visual task compatibility and flight crew needs and performance. 85N19664

UTTL: Flight deck design methodology using computerized anthropometric models
AUTH: A/STONE, G.; B/MCCAULEY, H.
PAA: B/(Douglas Aircraft Co., Long Beach, CA) IN: Aerospace Behavioral Engineering Technology Conference, 3rd, Long Beach, CA, October 15-18, 1984, Proceedings (A86-26001 10-54). Warrendale, PA, Society of Automotive Engineers, Inc., 1984, p. 9-16.
ABS: A new 'inside out' flight deck design methodology has been developed, in which the flight crew member is the logical starting point. Several computer models that simulate varying pilot sizes, proportions, reach, and vision capabilities are created and utilized to generate the required 'envelopes' of vision, reach, and motion for the entire range of the pilot population. These envelopes are then employed to define the internal geometric relationships of the flight deck and its components. The methodology is described, including discussions of the aspects of defining the user population, generation of crew sample, creating a three-dimensional operator model, determining functional envelopes, and component integration. Design diagrams are included.
RPT#: SAE PAPER 841472 84/00/00 85A26003

AUTH: UTTL: Cockpits for 2010 and beyond
A/SUMMERS, P. I.
PAA: A/(McDonnell Aircraft Co., St. Louis, MO) IEEE
Aerospace and Electronic Systems Magazine (ISSN
0885-8985), vol. 1, Feb. 1986, p. 17-20.

ABS: A proposed cockpit design for fighter aircraft is
described. The ground-based mission planning system is
discussed. The use of a forebody concept to
accommodate the physiological needs of the crew is
examined. An armrest control module is proposed for
controlling attitude and thrust. The encapsulation of
the crew station and display systems such as the
helmet mounted sight and display system are studied.
The application of artificial intelligence and
biocybernetics to the cockpit of the aircraft is
analyzed.   86/02/00   86A31849

AUTH: UTTL: Helmet mounted displays for tactical aircraft
A/SYLVESTER, WILLIAM A.
PAA: A/(Kaiser Aerospace and Electronic Corp., Kaiser
Electronics Div., San Jose, CA) SAFE Journal, vol.
17, Summer 1987, p. 24-28.

ABS: The need for a helmet-mounted display in the tactical
cockpit is examined. An integrated system approach,
referred to as 'Agile Eye', for the helmet-mounted
display system is described. The proposed integrated helmet
display system can protect the pilot's head from
impact, provide oxygen, communication, and eye
protection from the sun and wind blast, and weighs
less than the currently used lightweight Air Force
helmet and oxygen mask. The advanced electromagnetic
head tracking system will provide targeting cues,
weapon status, aircraft attitude, and performance
parameters to the pilot. Diagrams of the components of
the Agile Eye system are presented.   87/00/00
87A47112

AUTH: UTTL: Helmet mounted telescope
A/TASK, H. L.; B/BATES, C., JR.   CORP: Department of
the Air Force, Washington, D.C.

ABS: An improved helmet is provided including means to
telescopically acquire an image of a field of view,
which comprises, a telescopic optical system including
an objective lens mounted to said helmet above the
line of sight of the wearer, a light-conducting fiber
optics bundle mounted to said helmet for receiving the
image from the objective lens, and collimating lens
for receiving the image from the fiber optics bundle
and projecting the image onto a helmet-mounted visor
in the line of sight of the wearer. A shutter,
remotely controllable by the wearer, may be disposed
intermediate the objective lens and display to

selectively block transmission of the image.
RPT#: AD-D011355 US-PATENT-4,465,347
US-PATENT-APPL-SN-441814 US-PATENT-CLASS-350-538
82/11/15   85N16467

AUTH: UTTL: Perceptual organisation and information
management
A/TAYLOR, R. M.   CORP: Royal Air Force Inst. of
Aviation Medicine, Farnborough (England).   In AGARD,
Information Management and Decision Making in Advanced
Airborne Weapon Systems 28 p(SEE N87-29503 24-06)

ABS: The changing requirements for information processing
and control and the development of the information
management function are reviewed through the history
of the aircraft cockpit. Information management was
once entirely carried out by the pilot but now this
function seems likely to be shared between the pilot
and adaptive automation. Human information management
begins with perceptual organization. Gestalt thinking
on perceptual organization is reviewed with reference
to the information processing approach to human
cognition and in particular to the operations of
selective attention, working memory and the linking of
perception and thought. Perception can be facilitated
through the design of information displays. The
influence of the principles of perceptual organization
on the design of the dialogue across the human machine
interface is reviewed with particular reference to the
integration and differentiation of flight information.
Three experiments are reported that are relevant to
the use of color as an organizational factor in
complex pictorial computer generated displays.
87/02/00   87N29514

AUTH: UTTL: Progress report on an eye-slaved
area-of-interest visual display
A/TONG, H. M.; B/FISHER, R. A.   CORP: Singer Co.,
Silver Spring, Md.   CSS: (Link Simulation Systems
Div.)   In AF Human Resources Lab. The IMAGE 3 Conf.
Proc. p 279-294 (SEE N85-17962 09-01)

ABS: A dome-projection real-image system based on an
eye-slaved area-of-interest (AOI) concept has been
under development for some time at the Link Flight
Simulation Division of The Singer Company. The Link
approach provides a high-resolution area set within a
wide-field-of-view background. The display image is
presented to the trainee using light valve projection
on a dome screen, with the high-resolution AOI inset
slaved to the trainee's eye line of sight. The display
system integration program at Link has progressed past the
development program at Link and is undergoing
proof-of-concept test and evaluation. The system

approach and preliminary test findings are discussed in this paper.

RPT#: AD-P004326   84/09/00   85N17980

UTTL: A thin film electroluminescent display for cockpit applications

AUTH: A/VICK, G. L.; B/SHEPHARD, J. P.; C/RUNYAN, W. G.; D/TRCKA, J. S.

PAA: D/(Rockwell International Corp., Cedar Rapids, IA)
IN: Specialists' Meeting on Advanced Cockpit Design, Grapevine, TX, October 3, 4, 1984, Proceedings (A86-18451 06-06). Alexandria, VA, American Helicopter Society, 1984. 12 p.

ABS: For aircraft cockpit applications, thin films electroluminescent (TFEL) flat panel displays must be sunlight-readable and sufficiently rugged to sustain combat mechanical, thermal, and other stresses. In addition, panel reflectivity must be lower than for conventional applications. Attention is presently given to a TFEL system developed for the A-10 ground support aircraft, with a view to its display driver control circuitry, display memory, character interface circuitry, and power supply design. Preliminary results are presented.   84/00/00   86A18456

UTTL: Thin film electroluminescent (TFEL) display optimized for cockpit applications

AUTH: A/VICK, G. L.; B/RUNYAN, W. G.; C/COLTON, R. F.; D/THORKILDSON, R. J.; E/TRCKA, J. S.

PAA: E/(Rockwell International Corp., Avionics Group, Cedar Rapids, IA)   IN: Advances in display technology V; Proceedings of the Meeting, Los Angeles, CA, January 24, 25, 1985 (A86-32314 14-31). Bellingham, WA, SPIE - The International Society for Optical Engineering, 1985, p. 71-74.

ABS: A thin film electroluminescent flat panel display, developed specifically for the aircraft cockpit is described. The film is a sandwich of Mn-doped ZnS between two layers of Y2O3. The features of the electrical drive, and an optical band pass filter are presented, and the problems of increasing light output from the display, reducing reflections, and enhancing contrast are discussed. Performance data on two sample displays are included.   85/00/00   86A32321

UTTL: Big Picture - Answer to the big problem?

AUTH: A/WALKER, K.   Flight International (ISSN 0015-3710), vol. 128, Nov. 2, 1985, p. 22-24.

ABS: 'Big Picture' is an experimental fighter cockpit instrument system whose large area display entirely replaces the conventional instrument panel. Big Picture will apprise pilots of enemy aircraft positions, those of friendly aircraft, air-to-air and surface-to-air missile threats, and terrain, on a 300-400 sq in screen which is touch-sensitive to permit selection of different data types. Helmets incorporating brain activity sensors that could be used to actively control the display are under development in conjunction with Big Picture.   85/11/02   86A17172

UTTL: Among the weeds at night - Transition to night NOE flying

AUTH: A/WANSTALL, B.   Interavia (ISSN 0020-5168), vol. 40, July 1985, p. 793-795.

ABS: An evaluation is made of the performance capabilities of helmet-mounted head-up electrooptical displays currently in use or under development, which are aimed at facilitating high performance, safe nap-of-the-earth flight operations at night for military helicopter pilots. Night vision goggles, which amplify nocturnal light levels, lack the capacity for direct superposition of essential flight information; this capability can be incorporated through the use of miniature CRTs, by which a combination of forward looking IR sensor imagery and flight data graphics can be projected directly into the helicopter pilot's eye.   85/07/00   85A41532

UTTL: Time runs out for the clockwork cockpit

AUTH: A/WARWICK, G.   Flight International (ISSN 0015-3710), vol. 129, April 26, 1986, p. 30-33.

ABS: The concept of an electronic cockpit began with the design of a CRT horizontal situation indicator for the 767, which led to an electronic attitude direction indicator, etc. Further integration and simplification of the displays permitted displacement of the flight engineer. Customer demands for the latest in technology spurred further cockpit automation, along with backup analog displays. Synoptic displays have been developed in order to extend the digital display formats, and retain their simplicity. From two-engine aircraft to four-engine aircraft such as the 747-400 under development. Similar upgrades are being introduced into the MD-80 series of aircraft, which will also carry wind shear alert capabilities. Additionally, the MD-88 will have either LCD or LED displays to replace electromechanical gages for engine instruments and fluids displays. Extensive upgrading of the redundant autopilot for the MD-11 will permit the aircraft to take corrective actions in the event of a malfunction. The success of the autopilot, and the basis for the decision to implement such an

innovation, is a function of the long experience of the manufacturer with the aircraft. 86/04/26
86A38701

UTTL: The fiber-optic helmet-mounted display
AUTH: A/WELCH, B.; B/SHENKER, M. CORP: CAE Electronics Ltd., Montreal (Quebec). In AF Human Resources Lab. The IMAGE 3 Conf. Proc. p 345-361 (SEE N85-17962 09-01)
ABS: The feasibility of the fiber optic helmet mounted display (FOHMD) concept has been demonstrated on a breadboard system installed on a simulator at the Air Force Human Resources Laboratory (AFHRL). Behavioral and engineering evaluation are currently being conducted to determine the optimum design specification for an Engineering Prototype scheduled for completion in late 1984. This paper describes the significant engineering aspects of the FOHMD together with the exploratory program for improving its performance.
RPT#: AD-P004330 84/09/00 85N17984

UTTL: Engineering and human visual considerations in development of a fibre optic helmet mounted display
AUTH: A/WELCH, B. L.; B/KRUK, R.
PAA: B/(CAE Electronics, Ltd., Montreal, Canada) IN: Advances in flight simulation - visual and motion systems: Proceedings of the International Conference, London, England, Apr. 29-May 1, 1986 (A87-44708 19-53). London, Royal Aeronautical Society, 1986, p. 295-313.
ABS: The design requirements and development of a fiber optic helmet-mounted display (FOHMD) are described. The FOHMD is applicable in ground-based and airborne operational and training devices. Methods for developing a helmet display that has a field of view of 100 deg horizontal x 60 deg vertical, with separate eyepieces which have an overlap of 25-40 deg, and a resolution of about 1 arcmin/pixel are discussed. The FOV and resolution requirements determine the hardware characteristics. Luminance levels close to normal daylight levels are determined by combining optical characteristics of display devices, relay optics between display and fiber optic cables, the transmission of fiber optic cables, and the transmission of helmet optics. Various devices for the color CRTs are examined. Consideration is given to factors which affect performance: the exit pupil, image stability, and eye tracking of the FOHM.
86/00/00 87A44727

UTTL: Principles of S-C-R compatibility with spatial and verbal tasks - The role of display-control location and voice-interactive display-control interfacing
AUTH: A/WICKENS, C. D.; B/VIDULICH, M.; C/SANDRY-GARZA, D.
PAA: A/(Illinois, University, Savoy and Urbana, IL); C/(Illinois, University, Urbana, IL) Human Factors (ISSN 0018-7208), vol. 26, Oct. 1984, p. 533-543.
ABS: A pilot's tasks may be categorized into those that demand predominantly verbal operations and those that are spatial. Two experiments that define two principles of compatibility of interfacing such tasks with displays and controls are described. The first, based upon hemispheric-laterality effects, defines compatibility according to the display location and the response hand; the second defines compatibility according to the modality of display (auditory and visual) and response (manual and speech). Verbal tasks are best served by auditory inputs and speech response, whereas spatial tasks are best served by visual-manual channels. In both experiments, these principles of compatibility are confirmed under dual-task conditions. The implications for cockpit design are indicated. 84/10/00 85A21613

UTTL: Factors affecting dwell times on digital displaying
AUTH: A/WILLIAMS, A. J.; B/HARRIS, R. L., SR. CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.
ABS: A series of exploratory tests were conducted to investigate the effects of advanced display formats and display media on pilot scanning behavior using Langley's oculometer, a desktop flight simulator, a conventional electro-mechanical meter, and various digital displays. The primary task was for the test subject to maintain level flight, on a specific course heading, during moderate turbulence. A secondary task of manually controlling the readout of a display was used to examine the effects of the display format on a subject's scan behavior. Secondary task scan parameters that were evaluated were average dwell time, dwell time histograms, and number of dwells per meter change. The round dial meter demonstrated shorter dwell times and fewer dwells per meter change than the digital displays. The following factors affected digital display scanning behavior: (1) the number of digits; (2) the update rate of the digits; (3) the display media; and (4) the character font. The size of the digits used in these tests (0.28 to 0.50 inches) did not affect scan behavior measures.
RPT#: NASA-TM-86406 NAS 1.15:86406 85/04/00 85N24722

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-LS-156	ISBN 92-835-0456-9	UNCLASSIFIED

5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title	
	VISUAL EFFECTS IN THE HIGH PERFORMANCE AIRCRAFT COCKPIT

7. Presented at

8. Author(s)/Editor(s)	9. Date
Various	April 1988

10. Author's/Editor's Address	11. Pages
Various	152

12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors	
Visual perception Pilots (personnel) Cockpits	Display devices Human factors engineering, France

14. Abstract

Visual is the key sensory mode by which a pilot receives the vast majority of the information required to successfully fly the aircraft and accomplish his mission. Visual information is received both directly (viewing through the windscreen, heads-up display and visor) and indirectly (viewing instruments, graphics displays and imaging displays) in a continuous stream. The ability of the pilot to perceive, assimilate and act on this vast amount of visual information greatly depends on the quality of the presentation of this information. There are many factors that can reduce the effective visual capability of the pilot. It is the purpose of this Lecture Series to present many of these factors and discuss their effect on vision and visual performance.

This Lecture Series, sponsored by the Aerospace Medical Panel of AGARD, has been implemented by the Consultant and Exchange Programme. Keywords:

AGARD Lecture Series No.156
Advisory Group for Aerospace Research and Development, NATO
VISUAL EFFECTS IN THE HIGH PERFORMANCE AIRCRAFT COCKPIT
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152 pages

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AGARD-LS-156

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